Sacramento River Basinwide Water Management Plan

Groundwater Hydrology
January 2003

Foreword

Meeting the future water supply for California is no easy task. As surface water sources strain under the demand, groundwater resources become more important. The State's groundwater resources must, in turn, be monitored closely and managed responsibly.

This report, prepared by the California Department of Water Resources' Northern District, concerns groundwater resources within the Sacramento Valley and Redding groundwater basins. It supplements a series of technical memoranda prepared by two consulting firms – CH2M Hill and Montgomery Watson – that outlined the overall basinwide management strategy.

This report emphasizes the service areas associated with Sacramento River Settlement Contractors participating in the development of the ongoing Basinwide Water Management Plan, which is coordinated by the Bureau of Reclamation to meet the requirements of a January 1997 Contract Renewal Memorandum of Understanding (MOU) between the Settlement Contractors and the United States of America. The report is a comprehensive assessment of the occurrence, movement, and chemistry of groundwater in portions of the Sacramento Valley associated with the Settlement Contractor service areas. It also assesses the conjunctive management potential in each of the service areas.

For further information on the Sacramento River Settlement Contractors report, contact Toccoy Dudley, Chief, Groundwater Section, DWR Northern District, 2440 Main Street, Red Bluff, California 96080-2356; (530) 529-7383, tdudley@water.ca.gov.

Dwight P. Russell, Chief
Northern District

Contents

References and Plates 171

Tables

Figures

STATE OF CALIFORNIA
Gray Davis, Governor

THE RESOURCES AGENCY
Mary D. Nichols, Secretary for Resources

DEPARTMENT OF WATER RESOURCES
Thomas M. Hannigan, Director

Steve Macaulay Chief Deputy Director	Jonas Minton Deputy Director	Raymond D. Hart Deputy Director	Pete Garris Deputy Director
L. Lucinda Chipponeri Deputy Director	Peggy Bernardy Chief Counsel		

DIVISION OF LOCAL ASSISTANCE
Naser J. Bateni, Chief

NORTHERN DISTRICT
Dwight P. Russell, District Chief
William D. Mendenhall, Chief, Resources Assessment Branch

This report was prepared by:
Dan McManus, Associate Engineering Geologist, Northern District
J. Noel Eaves, Associate Engineering Geologist, Northern District
William M. Ehorn, Associate Engineering Geologist, Northern District
Kelly Staton, Engineering Geologist, Northern District
Jason Jurrens, Engineer, WR, Northern District
Michael Ward Engineer, WR, Northern District
Jean Woods, Associate Land & Water Use Analyst, Central District
Sandra Maxwell, Engineer, WR, Central District

With assistance from:
Todd Hillaire, Associate Engineer, WR, Northern District
Pat Parsons, Research Analyst I, GIS, Northern District
Deborah Spangler, Graduate Student Assistant, Northern District
John Ayres, Graduate Student Assistant, Northern District
Kim Rosmaier, Land & Water Use Analyst, Central District

Under the direction of:
Toccoy Dudley, Chief, Groundwater Section

Introduction

Introduction

In 1996, eight Sacramento River Settlement Contractors (SRSC) commenced litigation against the United States of America and others for the purposes of establishing that Section 3404(c)(3) of the Central Valley Project Improvement Act (CVPIA) does not apply to Sacramento River water rights settlement contracts. A settlement was reached in that litigation in January 1997, when the federal defendants agreed that Section 3404(c)(3) of CVPIA does not apply to the Sacramento River settlement contracts. As part of that settlement, the SRSCs and the U.S. Bureau of Reclamation (USBR) entered into a "Memorandum of Understanding Between Named Sacramento River Settlement Contractors and the United States of America for the Preparation of Data in Aid of the Renewal of Settlement Contracts," commonly referred to as the Contract Renewal MOU. The Contract Renewal MOU identified the following four major types of data or documents that were to be prepared as an aid in contract renewal negotiations:

1. an update and extension of the 1956 Cooperative Study
2. a Basinwide Water Management Plan for the Sacramento River
3. contracting principles
4. discussions of obligations to meet water quality, endangered species, and other environmental needs of the San Francisco Bay/ Sacramento-San Joaquin Delta

Following the completion of a scoping report in May 1998, the Basinwide Water Management Plan (BWMP) was initiated in December 1999 to meet the requirements of the Contract Renewal MOU. The BWMP is a joint effort by the SRSCs and the USBR, with assistance provided by the California Department of Water Resources (DWR). This report has been prepared by DWR in support of the BWMP. Study sponsors that were signatories to the Contract Renewal MOU include:

Glenn-Colusa Irrigation District (GCID)
Provident Irrigation District (PID)
Princeton-Codora-Glenn Irrigation District (PCGID)
Maxwell Irrigation District (MID)
Reclamation District No. 108 (RD 108)
Sutter Mutual Water Company (SMWC)
Pelger Mutual Water Company (PMWC)
Natomas Central Mutual Water Company (NCMWC)

In addition to the SRSC study sponsors, there are numerous other settlement contractors on the Sacramento River. Principal among these other contractors are Anderson-Cottonwood Irrigation District (ACID) and Reclamation District 1004 (RD 1004). Representatives from ACID and RD 1004 served on the BWMP Executive Committee.

Participating agencies in the BWMP and signatories to the MOU for the federal and state governments are the USBR and DWR, respectively. Other SRSCs, in addition to those listed above, reviewed and provided input during the development of the plan but were not signatories to the MOU, did not participate on the Executive Committee, and are not specifically addressed in this report.

Relationship to Other Technical Memoranda

This report is part of a series of seven BWMP technical memoranda developed to assess specific technical issues such as water requirements, water resources, water needs, and management options. The technical memoranda were produced by CH2MHill and Montgomery Watson 1999–2001 and are as follows:
TM 1: Project Goals and Objectives
TM 2: Current and Future Water Requirements
TM 3: Water Resources Characteristics
TM 4: District Need for Water and Basinwide Water Balance
TM 5: Water Management Supply Options
TM 6: Future Water Management Alternatives
TM 7: Implementation Plan

This report supports, and is a companion document to, TM 3. Together, these two technical documents assess water resources for areas encompassing the study participants.

This report presents the results of a groundwater resource assessment for areas within the Sacramento Valley and Redding groundwater basins. The Sacramento River Settlement Contractors included in this study are listed in Table 1 and shown on Plate 1. Table 1 also lists the groundwater subbasins and counties associated with the individual SRSC service areas.

Table 1
Sacramento River Settlement Contractors participating in the Basinwide Water Management Plan

SRSC	Groundwater subbasin	County(s)
Anderson-Cottonwood Irrigation District	Anderson, Enterprise & Bowman	Shasta & Tehama
Glenn-Colusa Irrigation District	Colusa	Glenn & Colusa
Provident Irrigation District	Colusa	Glenn & Colusa
Princeton-Codora-Glenn Irrigation District	Colusa	Glenn & Colusa
Maxwell Irrigation District	Colusa	Colusa
Reclamation District 108	Colusa	Colusa & Yolo
Reclamation District 1004	West Butte	Butte, Glenn, Colusa & Sutter
Pelger Mutual Water Company	West Sutter	Sutter
Sutter Mutual Water Company	West Sutter	Sutter
Natomas Central Mutual Water Company	North American	Sutter, Placer & Sacramento

Groundwater resources of the Sacramento Valley are detailed at several levels. At the regional level, a general discussion of groundwater resources for the Sacramento Valley and Redding groundwater basins is presented. At the groundwater subbasin and SRSC service area level, groundwater resources are analyzed and discussed in more detail. The more detailed analysis at this level includes a discussion of local groundwater quality, land subsidence, local groundwater management plans, and groundwater-related county ordinances.

Much of the information in this report was obtained from published reports, unpublished information, and data on file with DWR. Little new data were collected or developed as part of this investigation.

The hydrogeology in many areas of the Sacramento Valley is not understood because of the lack of basic groundwater data, such as groundwater levels and water well completion reports. Areas lacking in groundwater data typically correspond to regions where there is little groundwater development because surface water is historically the primary source for irrigation. Many of the SRSCs participating in the BWMP fall within these regions of limited groundwater data.

Characterization of the aquifer system associated with each of the SRSCs participating in the BWMP is based on available groundwater data. The parameters included in the aquifer characterization are listed below:

groundwater levels
groundwater movement
groundwater extraction
well yield
well depth
specific capacity
groundwater storage capacity
groundwater in storage
changes in groundwater in storage from 1989 to 1999
conjunctive management potential

Groundwater Levels

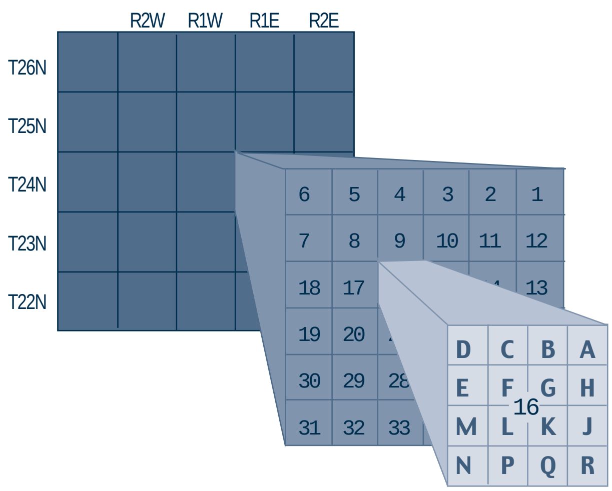
Groundwater levels fluctuate because of changes in the amount of groundwater in aquifer storage. Factors that affect groundwater in storage are the amounts of aquifer recharge and discharge. The aquifer system is recharged from subsurface inflow to the basin and percolation from precipitation, streams, irrigation water, and sometimes from water introduced to the aquifer system during inelastic land subsidence. Aquifer discharge occurs when groundwater is extracted by wells, discharges to streams, evapotranspires from phreatophytes, or flows out of the groundwater basin in the subsurface. Dry years cause groundwater levels to gradually decline because more water is discharged than recharged. During wet years, groundwater levels typically recover because more water is recharged than discharged.

Analyses of groundwater levels in this report are based on data collected by DWR and other data collection cooperators. Groundwater levels are usually measured twice a year, once in the spring when groundwater levels are at their highest, and once in the fall when they are near their lowest. Groundwater levels are typically measured to the nearest one-tenth of a foot using an electric sounder or a steel tape.

The groundwater level data were used to develop hydrographs for selected monitoring wells. The hydrographs were then used to analyze the groundwater level time-history for the well. The time-history was used to estimate the seasonal and long-term fluctuations in groundwater levels at the groundwater subbasin and SRSC service area level.

The monitoring wells are numbered using the State Well Numbering System. The State Well Numbering System identifies each well by its location according to the township, range, section, and tract system. Figure 1 illustrates the State Well Numbering System.

Figure 1
California State Well Numbering System



Select hydrographs for the individual SRSC service areas are shown in Chapter 3. The data can be retrieved by a graphical map interface or by basin according to the State Well Number from the DWR Web site.

When reviewing hydrographs, note that the dots indicate a static groundwater level measurement, other symbols indicate a measurement that has been qualified as questionable. Breaks in a hydrograph represent missing measurements. DWR assigns a numerical code to all questionable groundwater level measurements to increase the accuracy of data analysis. Questionable measurement codes are used to differentiate between static and pumping groundwater level measurements, and to identify if nearby wells are pumping during the measurement. A key to the types of questionable measurement codes used with the Internet hydrographs is available on the DWR Web site.

When interpreting changes in groundwater levels, care should be used to compare only those measurements taken during similar times of the year. Before 1990, much DWR groundwater level data listed only spring and fall measurements. After 1990, however, summer measurements were added for some wells. When using a hydrograph to compare multiple years of groundwater level data, comparison of the spring measurements is recommended.

Groundwater Movement

Groundwater level data were also used to develop groundwater elevation contours for the Sacramento Valley. Based on this information, the direction of groundwater flow and the gradient of groundwater movement were estimated for each of the SRSC service areas.

Groundwater contour maps were constructed using a computer-aided groundwater surface-modeling program. The contouring software generates approximate contour locations based on a network of triangulated grids. Accuracy of the groundwater elevation contours varies with respect to the data density and the groundwater gradient. Additional editing of contour locations was based on general knowledge of the hydrogeologic characteristics of the region.

The groundwater elevation contours were developed using measurements from wells that represent different aquifer conditions: confined, semi-confined, unconfined, or mixed aquifer conditions. Within the same local area, the groundwater level in a shallow well constructed in the unconfined portion of the aquifer system may be significantly different from the groundwater level in a deep well constructed in the confined portion of the aquifer system. Because of the potential differences in groundwater levels between different levels of aquifer confinement, care should be taken when using the contour maps to interpret groundwater occurrence and movement at a local scale. The groundwater elevation contours provide a good regional estimate of groundwater movement within the mid-to-upper portion of the aquifer system. Contour maps in Plates 3 and 4 show the movement and direction of groundwater. Groundwater movement for each SRSC service area is discussed in Chapter 3.

Groundwater Extraction

Knowing how much groundwater is being extracted from a basin contributes to a better understanding of the current groundwater development and management methods that are most appropriate for maintaining a sustainable groundwater resource. One method of measuring groundwater extraction is by direct metering of individual production wells within the basin. However, in most areas of the Sacramento Valley, agricultural wells are not metered and groundwater extraction cannot be directly monitored. A second method, and the one used in this study, estimates the total groundwater extraction by the water balance approach.

To use the water balance approach, groundwater demands were determined using land use data developed by DWR. Land use data includes estimates of the agricultural demand for water and the surface water delivery for a given area. In areas having a mixed supply of surface water and groundwater, the difference between the agricultural demand and the surface water delivery is assumed to be equal to the amount of groundwater extraction.

Land use data were developed in the mid-1990s when DWR conducted land use surveys of counties in the Sacramento Valley. These surveys determined the gross acreage for various crops grown during the survey year. The gross acreage is typically reduced by 5 percent to account for nonirrigated lands such as roads, ditches, and canals. The results of the land use surveys show the estimated net irrigated acreage of each SRSC service area. Collectively, the water use data and irrigated acreage data are used to estimate the amount of groundwater applied within each SRSC service area, using the water balance approach.

A map was developed for each SRSC service area to illustrate lands irrigated with surface water, groundwater, or a combination of surface water and groundwater, referred to as a mixed source. The water use areas do not represent specific areas of application for any single year. Rather, these areas represent the potential for application of water from the source indicated. Water use maps for each SRSC service area are presented in Chapter 3.

The groundwater extraction estimates do not include domestic, municipal, and industrial uses. In most areas, the amount of groundwater extracted from private wells for domestic and industrial use is considered minor in comparison with agricultural use. Groundwater extraction data and water use figures for each SRSC service area are presented in Chapter 3.

Well Yield

Well yield is the maximum amount of groundwater that can be continuously extracted from a well. Well yield values are a function of well size, well performance, and aquifer productivity. Sources of well yield data reviewed for this investigation include Well Completion Reports filed with DWR and records of pump test conducted by local utilities and published by USGS.

Well yield data listed in Well Completion Reports are often derived using a variety of pumping methods, which often produce variable results. Well yield data listed in the Well Completion Reports are often collected during well drilling or development, and are commonly a function of the particular pumping test method rather than an accurate indication of maximum well yield for a given area. Well yield data from Well Completion Reports should serve only as a general approximation of well yield.

A more accurate estimate of well yield is provided through utility pumping tests. Utility pumping tests are typically performed using the existing pump motor and bowls that were designed for each well. Utility pumping test records provide an accurate estimate of well yield.

In the 1940s, USGS collected utility pump test records and, in 1961, published a report titled *Geologic Features and Ground-Water Storage Capacity of the Sacramento Valley California*. In the report, USGS gathered well yield data from large-capacity irrigation, industrial, and municipal wells in 21 study areas within the Sacramento Valley through 1948. Well yield data presented in the USGS report are used to characterize well production in the SRSC service areas. Summary tables showing well yield data for each SRSC service area are provided in Chapter 3.

Well Depth

The depths of existing wells in each SRSC service area were used to estimate the amount of available groundwater in storage and to assess potential impacts of increased groundwater development on a region. In many parts of the Sacramento Valley, the potential impact of groundwater extraction on shallow wells is the limiting factor in the amount of groundwater that can be extracted from a particular area. Extracting too much groundwater can adversely affect shallow wells by causing groundwater levels to be lowered below the pump bowls or the bottom of the well, resulting in an unusable well.

Well depths were analyzed for domestic and irrigation water wells in areas where sufficient well depth information was available. The well depth data were plotted in histograms and cumulative frequency distribution curves for analysis. The well depth data were collected from Well Completion Reports filed at DWR.

Specific Capacity

Specific capacity is a method of measuring well productivity. Specific capacity of a well is the extraction rate divided by the total drawdown after a specified period. Specific capacity reflects the transmissibility of the aquifer and, to a lesser degree, the efficiency of the well. Specific capacity is usually reported in gallons per minute per foot of drawdown, with the elapsed time the well was pumped before the measurement. Sources of specific capacity data reviewed for this investigation include Well Completion Reports and utility pumping test records published by USGS.

Where the SRSC service area Well Completion Reports listed well yield with pumping drawdown, an analysis of specific capacity for the area was conducted. In areas where the Well Completion Reports did not have adequate information to calculate specific capacities, data from other investigations were used.

Specific capacity data in the Sacramento Valley were also published in the 1961 USGS report. USGS data were used for those areas where no additional specific capacity information was available. Specific capacity data are provided for each SRSC service area in Chapter 3.

Groundwater Storage Capacity

Estimates of groundwater storage capacity, groundwater in storage and historical change in groundwater storage were developed for each SRSC study area. Groundwater storage estimates were calculated by multiplying the total surface area of the SRSC by the specified saturated thickness of the aquifer. This value was then multiplied by the estimated average specific yield of the aquifer system. Specific yield is defined as the ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil (Fetter 1988). The storage estimates were developed for a better understanding of the groundwater resources at the SRSC service area level.

The series of groundwater storage estimates were calculated as follows:

$$S = Ta * Sy * A$$

Where S = Groundwater storage:
Ta = Specified thickness of the aquifer system
Sy = Average specific yield of the aquifer system
A = Service area for the Sacramento River Settlement Contractor

Groundwater storage capacity is defined as the maximum volume of fresh groundwater capable of being stored within an aquifer beneath a given area. Using the equation above and the saturated thickness of the aquifer system from the base of fresh water to the highest acceptable groundwater level, the maximum storage capacity was estimated for each SRSC service area.

In most of the northern SRSC service areas, the current aquifer system is close to maximum storage capacities. For these areas, the estimates of groundwater storage capacity are similar to the estimated total amount of groundwater currently in storage.

Groundwater in Storage

Groundwater in storage is the volume of groundwater currently in storage. Estimates of groundwater in storage can refer to the storage volume for the entire freshwater portion of the aquifer system or for the aquifer storage over a specified interval of saturated thickness. Using the formula above, estimates of groundwater in storage for each SRSC service area were calculated for four levels of saturated aquifer thickness (Ta). Descriptions of the four storage estimates are as follows:

1. Estimated total groundwater in storage. This estimate represents the total amount of fresh groundwater in storage beneath the SRSC service area. The depth to the base of fresh water is derived from criteria established in DWR Bulletin 118-6, which assumes the base of fresh water to be less than or equal to the depth where the specific conductance of the groundwater exceeds 3,000 micromhos/cm. Storage estimates based on the total saturated thickness of the freshwater aquifer beneath a given SRSC service area are intended to serve as a general reference of aquifer size, and not as a guideline of potential production capabilities. Attempts to use all the fresh groundwater in storage would result in disastrous consequences to the groundwater resource, local groundwater users, and surrounding communities.

2. Estimated groundwater in storage to a depth of 200 feet. DWR has historically assumed that the average amount of usable groundwater in storage is the amount to a depth of 200 feet. In much of the Sacramento Valley, this approach significantly overestimates the amount of usable groundwater in storage. The controlling factor in determining the available groundwater in storage is the depth and perforation interval of existing wells. Current understanding of the Sacramento Valley Groundwater Basin indicates that a lowering of groundwater levels to a uniform depth of 200 feet below ground surface would significantly impact most, if not all, groundwater users in the surrounding region.

3. Estimated groundwater in storage to a depth where 50 percent of irrigation wells in the SRSC service area would be dewatered. This estimate of usable groundwater storage is based on the uniform lowering of groundwater levels to a depth that would cause 50 percent of the irrigation wells to be dewatered.

4. Estimated groundwater in storage to a depth where 10 percent of irrigation wells in the SRSC service area would be dewatered. This estimate of usable groundwater storage is based on the uniform lowering of groundwater levels to a depth that would cause 10 percent of the irrigation wells to be dewatered.

The storage estimates were developed to generate an understanding of the amount of groundwater storage that exists within the natural basin area and within the existing production wells used for irrigation purposes. Because of the numerous shallow domestic wells within the Sacramento Valley, the actual amount of usable groundwater storage would be much less than the volumes estimated under any of the criteria above.

Concern about the potential impacts to shallow domestic wells near SRSC service areas will limit the amount of acceptable drawdown that can occur within the area. Moreover, extracting groundwater in amounts similar to those calculated by the criteria above would create concerns about potential land subsidence and degradation of groundwater quality.

These estimates of groundwater storage should not be used for water inventory analysis or as criteria for potential development within a conjunctive management scenario. The actual amount of usable groundwater in storage can only be determined through active management and adequate monitoring of the groundwater resource.

Changes in Groundwater in Storage, 1989-99

The changes in groundwater in storage are defined as the spring-to-spring change in storage within the unconfined portion of the aquifer system. For each SRSC service area, the change in groundwater in storage is graphed based on the spring-to-spring groundwater level change in the unconfined monitoring wells over the 10-year period from 1989 to 1999. The graphs illustrating the change in groundwater in storage start with a baseline of zero for spring 1989 because that season closely characterizes groundwater conditions associated with an average water year. In subsequent years, changes in groundwater in storage are shown as cumulative change and are calculated based on the difference between groundwater levels during the baseline year (spring 1989) and the groundwater levels for spring of a given year. In areas with multiple unconfined monitoring wells, the spring- to- spring change in groundwater in storage is based on the average change in groundwater levels from all of these wells. The monitoring wells used to calculate historical changes in groundwater in storage are listed on the respective graph for each area.

The individual spring-to-spring storage estimates are calculated using the formula above, with the specified saturated thickness equal to the average spring-to-spring change in groundwater level.

In areas with an adequate number and distribution of unconfined monitoring wells, the change in groundwater in storage is considered a good approximation of regional conditions. In SRSC service areas with a limited number of unconfined or semi-confined groundwater-level monitoring wells, the estimates of change in groundwater in storage characterize a more local area.

Conjunctive Management Potential

Groundwater in the Sacramento Valley is commonly misperceived as a vast, untapped resource. Although a significant amount of fresh groundwater exists in storage, poorly planned and uncoordinated use of this resource could have potentially serious consequences. Junior appropriative water right holders in the Sacramento Valley could be impacted through uncoordinated use and improper management of the groundwater resources. Groundwater seepage from the Sacramento Valley into the Sacramento and Feather rivers is a major contributor to in-stream flow. Increases in groundwater extraction without coordinated recharge efforts could reduce or reverse this seepage, causing depletion of in-stream flow.

Conjunctive management of surface water and groundwater is one way of increasing the dry-year water supply reliability without incurring negative impacts. However, optimum conjunctive management practices will require a fundamental change in the current agreements that govern surface water deliveries. The current agreements do not provide sufficient flexibility of surface water deliveries to allow for optimal aquifer recharge. Conjunctive management methods call for increasing surface water deliveries for aquifer recharge during periods of excess surface water availability. The recharged groundwater is then used to supplement water needs during periods of diminished surface water supply.

In much of the Sacramento Valley, informal conjunctive management of surface and groundwater resources is already occurring. A preliminary assessment of the conjunctive management potential for each of the SRSC service areas is presented in Chapter 3. This assessment is based on available aquifer storage, existing facilities, and institutional issues, as well as information from published and unpublished studies developed by DWR and others. In all SRSC service areas, additional studies are needed to quantify the conjunctive management potential.

Sacramento Valley Groundwater Basin Regional Hydrology

Sacramento Valley Groundwater Basin Regional Hydrology

The Sacramento Valley Groundwater Basin comprises one of California's largest and most productive groundwater basins. The Valley is a nearly flat alluvial plain that extends approximately 180 miles from the Sacramento-San Joaquin Delta in the south to Redding in the north, and stretches approximately 50 miles from the Sierra Nevada foothills in the east to the Coast Ranges in the west. The Sacramento Valley is an asymmetric structural trough filled with sediments to a depth of approximately 3 to 5 miles. These sediments have been deposited almost continuously since late Jurassic time (160 million years ago). Much of the groundwater in the deeper sediments, which were deposited in a marine environment, is saline or brackish. The younger sediments, derived from a continental source, overlie the marine sediments and generally contain fresh groundwater.

North of Red Bluff, an east-west trending series of folds in valley sediments separates part of the northern Sacramento Valley Groundwater Basin from the main portion to the south. This structure is referred to as the Red Bluff Arch. Based on this hydrogeologic separation, the Sacramento Valley has been divided into two main groundwater basin areas: the Redding and the Sacramento Valley groundwater basins.

More recently, it has been recognized that natural hydrologic boundaries that exist within the Redding and Sacramento Valley groundwater basins can lead to further subdivision within these main basins. Based on previous groundwater investigations, modeling studies, and review of groundwater level data, DWR has further delineated the Redding and Sacramento Valley groundwater basins into 25 groundwater subbasins. The subbasin areas are shown in Plate 1. These subbasins represent common hydrogeologic areas for assessment of local groundwater resources and contribute to an understanding of the natural relationship between surface hydrology and local groundwater systems.

Redding Groundwater Basin

The Redding Groundwater Basin comprises the northernmost portion of the Sacramento Valley. Bordered by the Klamath Mountains and Coast Ranges to the north and west, respectively, the Cascade Mountains to the east, and the Red Bluff Arch to the south, the Redding Groundwater Basin covers 510 square miles.

The surface topography of the basin is characterized as a dissected plain. Multiple east- and west-side tributaries flow into the Sacramento River, which serves as the primary drain of surface water and groundwater from the basin. Major east-side tributaries include Battle Creek, Cow Creek, and Little Cow Creek. Major west-side tributaries include Clear Creek, Dry Creek, and Cottonwood Creek. Elevations in the basin range from 400 feet along the Sacramento River to 800 feet along the upland reaches of the valley.

Surface and Subsurface Geology

Structurally, the Redding Groundwater Basin consists of a sediment-filled, symmetrical, southward-dipping trough formed by folding of the marine sedimentary basement rock (DWR 1968). These rocks are late Jurassic to late Cretaceous in age and are referred to as the Great Valley Sequence. Unconformably overlying the Great Valley Sequence is a thick sequence of interbedded, continentally derived, sedimentary and volcanic deposits of late Tertiary to Quaternary age.

Accumulation of late Tertiary sediments resulted in the deposition of two simultaneous, but different, formations in the western and eastern portions of the Redding Groundwater Basin. Along the west and northwest portions of the basin, the Tehama Formation overlies Great Valley Sequence rocks and dips eastward, extending beneath the valley floor, and forms the base of the continental deposits. These sediments were derived from the Coast Ranges to the west. Overlying basement rocks of the Cascade Range along the east and northeast margins of the basin, the Tuscan Formation dips westward, toward the valley axis, and serves as the base of continental deposits for the east and northeastern portion of the basin. The Tuscan Formation deposits are volcanic in origin and are derived from the Cascade Range.

The continental deposits are unconsolidated to semi-consolidated, and range in thickness from about 2,000 feet near the confluence of the Sacramento River and Cottonwood Creek to a veneer along the western basin boundary. These sedimentary deposits comprise the major water-bearing units in the basin. Basinwide analysis of well yields indicates that permeability of the water-bearing continental deposits is lowest around the margins of the basin and increases toward the central to south-central portion of the basin.

Fresh-Groundwater-Bearing Units

The base of fresh water in the Redding Groundwater Basin ranges from several hundred feet above the top of the Great Valley Sequence in the south-central portion of the basin to several hundred feet below the top of the Great Valley Sequence along the basin margins. Overlying the Great Valley Sequence, fresh-water-bearing units consist of unconsolidated to semi-consolidated continental sediments of late Tertiary to Quaternary age. Within these continental sediments, groundwater exists in the pore spaces between the individual grains of clay, silt, sand, and gravel.

The primary fresh water-bearing deposits in the basin are the Pliocene age volcanics of the Tuscan Formation and the Pliocene age continental deposits of the Tehama Formation. Less important water-bearing deposits in the Redding Groundwater Basin include the Pleistocene age older alluvium of the Riverbank and Modesto formations, and Holocene age alluvium, which are comprised of surficial alluvium and stream channel deposits.

Pliocene Age Volcanics. The Tuscan Formation is the main water-bearing formation along the east side of the Redding Groundwater Basin. Volcanic in origin, the Tuscan Formation was deposited during approximately the same geologic period as the Tehama Formation. Original deposition of the Tuscan Formation consisted of a series of interbedded volcanic lava flows, mudflows, conglomerate, tuff, and tuff breccia, resulting in formation thickness up to 1,600 feet. In the basin, periodic exposure and reworking of Tuscan volcanic material resulted in more permeable volcanic sand and gravel deposits that are interbedded with less permeable volcanic mudflows. Permeability of the Tuscan Formation is generally higher than that of the Tehama Formation. Volcanic sand and gravel deposits of the Tuscan Formation can provide well yields of up to 5,000 gpm to agricultural wells and higher-than-average yields to domestic wells in the basin. Groundwater in the Tuscan Formation occurs under unconfined, semi-confined, and confined conditions.

Pliocene Continental Deposits. The Tehama Formation is the main water-bearing formation along the west side of the Redding Groundwater Basin. The Tehama Formation accumulated as a series of coalescing alluvial fans along the eastern slope of the Klamath Mountains and Coast Ranges and consists of unconsolidated to semi-consolidated, interbedded clays, silts, and gravels (Russell 1931). Maximum thickness of the Tehama Formation in the basin is 2,000 feet near the south-central portion of the basin. Permeability of the Tehama Formation is moderate to high, with typical well yields ranging from 100 to 1,000 gpm (Pierce 1983). In central parts of the basin, adjacent to the Sacramento River, irrigation well yields as high as 2,000 gpm have been reported from the Tehama Formation. Groundwater in the Tehama Formation occurs under unconfined, semi-confined, and confined conditions.

Pleistocene Older Alluvium. The Pleistocene age older alluvial deposits include alluvial fan and stream terrace deposits of the Riverbank and Modesto formations.

Riverbank Formation. The Pleistocene Riverbank Formation is composed of terrace deposits that consist of poorly consolidated gravel, sand, and silt. These deposits are up to 200 feet thick and are typically found along the Sacramento River and adjacent tributaries. The Riverbank Formation is moderately to highly permeable and yields moderate quantities of groundwater to domestic wells. Groundwater occurs predominately under unconfined conditions.

Modesto Formation. Terrace deposits of the Pleistocene Modesto Formation are younger than the Riverbank Formation and are composed of unconsolidated, slightly to unweathered gravel, sand, silt, and clay, with a maximum thickness of approximately 200 feet. These deposits are seen along stream channels in the valley. Permeability of the Modesto Formation varies; and where areas of silt and clay predominate, well yields are limited. Well yields are higher in areas where gravels and sands prevail. Groundwater occurs under unconfined conditions.

Holocene Alluvium. Holocene age alluvium in the Redding Groundwater Basin consists of unconsolidated, unweathered gravel, sand, silt, and clay from stream channel deposits, and dredged gravel deposited by past mining activities. Alluvial deposition occurs within, and adjacent to, the Sacramento River and tributaries of Cottonwood, Cow, and Stillwater creeks. Alluvial thickness varies from 1 to 80 feet. Permeability is generally moderate, but may be extremely high where gravel-size deposits predominate. Well yields vary from moderate to high, with production as high as 2,000 gpm in some localized agricultural wells. Because of limited saturated thickness, alluvial deposits generally serve only local domestic needs and are not major groundwater-producing units for the basin.

Movement of Groundwater

Groundwater movement within the Redding Groundwater Basin was analyzed based on groundwater elevation contours developed for the Sacramento Valley. Sacramento Valley groundwater contours are shown in Plates 3 and 4. These contours were developed using March 1997 groundwater level data collected by DWR and local cooperators. Plate 3 shows the spring 1997 groundwater contours for the Sacramento Valley along with SRSC service areas. Plate 4 shows spring 1997 contours with flow direction arrows indicating the direction of groundwater movement. The flow arrows in Plate 4 show that for the basin, regional groundwater flows toward the Sacramento River. Separation of the southern Redding and northern Sacramento groundwater basins is indicated by the change in groundwater flow direction along either side of the Red Bluff Arch. Locally, the direction of flow is variable as groundwater typically moves toward the nearest tributary. Under current hydrologic conditions, the Sacramento River serves as a groundwater drain for the basin.

Sacramento Valley Groundwater Basin

The Sacramento Valley Groundwater Basin is the second largest groundwater basin in California next to the San Joaquin Valley. The basin extends southward from Red Bluff to the Sacramento-San Joaquin Delta, and is bordered by the Coast Ranges on the west, and the Cascade Range and Sierra Nevada mountains on the east. Covering 4,900 square miles, the Sacramento Valley Groundwater Basin includes all of Sutter County and parts of Yuba, Tehama, Glenn, Butte, Colusa, Yolo, Solano, Placer, and Sacramento counties.

Adjacent to the Sacramento River, along the north-south valley axis, the surface topography of the basin is a relatively flat alluvial plain. Toward the margins of the basin, the flat valley floor yields to low hills, dissected uplands, and alluvial fans of moderate relief. The one topographic anomaly along the valley floor consists of a 2,000-foot-high intrusion of late Cenozoic volcanic rock known as the Sutter Buttes. Located near the center of the valley floor, the Sutter Buttes comprise the highest elevation of all points in the valley and act as a barrier to groundwater flow. The constriction in the north-south direction of groundwater flow forces groundwater to the surface, forming wetlands on the west side of the Sutter Buttes.

Numerous tributaries contribute to the Sacramento River along its course through the basin. Most of the perennial flow occurs from tributaries along the basin's east side. The most prominent of these include the American, Bear, Yuba, and Feather rivers. The most prominent perennial creeks that occur on the east side of the basin include Butte, Chico, Deer, Honcut and Mill creeks. West-side tributaries include Putah, Cache, Stony, and Thomes creeks. These west-side creeks are largely ephemeral, with high flows occurring only during winter months.

Surface and Subsurface Geology

Structurally, the Sacramento Valley Groundwater Basin forms an asymmetrical trough tilting to the southwest, with a steeply dipping western limb and a gently dipping eastern limb (Page 1986). Older granitic and metamorphic rocks underlie the valley and form the bedrock basement, on which younger marine and continentally derived sediments and volcanic rock have been deposited. Along the valley axis, the basement is at considerable depth, ranging from 12,000 to 19,000 feet. The bedrock basement becomes shallower toward the margins of the valley (Helley and Harwood 1987). Immediately overlying the basement bedrock are Jurassic through Eocene age sandstone, shale, and conglomerate rocks of marine origin. Over most of the basin, groundwater within these sediments is saline or brackish.

Deposition of two simultaneous but different formations occurred in the western and eastern portions of the Sacramento Valley during late Tertiary time. Along the western portion of the basin, the Tehama Formation overlies late Cretaceous and early Tertiary marine sedimentary rocks, extending eastward and dipping beneath the valley floor. These sediments were derived from the Coast Ranges to the west and form the base of the continental deposits. Along the eastern and northeastern margins of the basin, the Tuscan and Mehrten formations dip westward toward the valley axis. The Tuscan and Mehrten formations are volcanic in origin and were derived from the Cascade and Sierra Nevada ranges, respectively. These formations are semi- to well consolidated and can attain a maximum thickness of up to 1,600 feet near the axis of the valley (based on preliminary data from ongoing investigations by DWR). Throughout most of the basin, these units are overlain by Pleistocene age older alluvium and Holocene age alluvium, which are 200 feet thick or less. The late Tertiary and younger units form the major fresh-water-bearing aquifer system in the Sacramento Valley Groundwater Basin.

Fresh-Groundwater-Bearing Units

The base of fresh water in the Sacramento Valley Groundwater Basin generally follows the contact between the top of the marine sedimentary deposits and the base of the continental deposits. Along the axis of the northern portion of the basin, the base of fresh water ranges from 2,200 feet below ground surface near Red Bluff, to about 1,100 feet in the area south of Chico. In the southern portion of the basin, the base of fresh water ranges from several hundred feet below ground surface near the Sutter Buttes, to more than 3,000 feet just south of Davis (Berkstresser 1973; DWR unpublished data 2000).

The following characterizations of hydrogeologic units for the Sacramento Valley Groundwater Basin focus on the major fresh-water-bearing units. These deposits are mostly late Tertiary and are grouped into eight regionally distinct water-bearing units. The groupings include Eocene age continental deposits, Miocene age marine and non-marine sediments, Mio-Pliocene age volcanics, Pliocene age continental deposits, Pliocene age volcanics, Pleistocene age older alluvium, and Holocene age alluvium.

Eocene Age Continental Deposits. Eocene age continental deposits primarily consist of the Ione Formation, which is exposed mainly on the southeast margin of the valley. The Ione Formation is stratigraphically the oldest fresh groundwater-bearing unit in the basin, occurring under confined conditions. Deposits of the Ione Formation include clay, sand, and sandy-to-gravelly clay, with a maximum thickness of 650 feet. The Ione Formation is characterized by low permeability and infiltration rates. Locally, the Ione Formation contains zones of brackish water.

Miocene Age Marine and Non-Marine Deposits. The Miocene age Neroly Formation extends in the subsurface throughout much of the Sacramento Valley. Sediments are up to 500 feet thick and consist of andesitic sandstone with interbeds of tuffaceous shales and occasional conglomerate lenses. The Neroly Formation contains fresh and saline, interstitial water with variable permeability under confined conditions.

Mio-Pliocene Age Volcanics. The Mehrten Formation extends along the east side of the Sacramento Valley from near Oroville to the southern end of the valley. The Mehrten Formation consists of a series of impermeable volcanic mudflows and tuff-breccia deposits that are interbedded with permeable volcanic silt, sand, and gravel. It extends beneath the surface, from its exposure in the Sierra Nevada foothills in the east to the Sacramento River in the west, attaining a maximum thickness of 500 feet. Volcanic "black sands" and gravels in the Mehrten Formation can be highly permeable, while mudflow deposits serve as confining units. Groundwater occurs under confined and unconfined conditions. The Mehrten Formation is an important groundwater-producing unit in the southeastern Sacramento Valley.

Pliocene Age Continental Rocks. The Laguna Formation generally overlies the Mehrten Formation in the southeast Sacramento Valley and consists of interbedded alluvial silt, clay, and fine sand with minor conglomerate lenses. Where sand predominates, the Laguna Formation is highly permeable, but average permeability is from low to moderate. The Laguna Formation can attain a thickness up to 450 feet, and groundwater in the formation occurs under confined, semi-confined, and unconfined conditions.

Pliocene Age Volcanics. The Pliocene age Tuscan Formation is the main water-bearing formation in the northeastern Sacramento Valley. The Tuscan Formation was deposited during approximately the same period as the Tehama Formation. The Tuscan Formation consists of a series of interbedded volcanic lava flows, mudflows, volcanic sandstone, conglomerate, and tuff. Maximum thickness of the formation is about 1,600 feet. Volcanic sand and gravel deposits of the Tuscan Formation can provide high yields to agricultural and domestic wells. Groundwater in the Tuscan Formation occurs under unconfined, semi-confined, and confined conditions.

Pliocene Age Continental Deposits. The Tehama Formation, which consists of thickly bedded deposits of silt and clay interbedded with thinner zones of lenticular sand and gravel, is the main water-bearing unit on the west side of the Sacramento Valley. Throughout much of the Tehama Formation, tuffaceous material, fine-grained sediments, and hardpan layers result in permeability values ranging from low to moderate. The Tehama Formation can attain a maximum thickness of 2,000 feet and groundwater occurs under unconfined, semi-confined, and confined conditions. The permeability of the Tehama Formation is typically less than that of the Tuscan Formation.

Pleistocene Age Older Alluvium. The Pleistocene age older alluvial deposits include alluvial fan and stream terrace deposits of the Riverbank and Modesto foormations.

> **Riverbank Formation.** The Riverbank Formation is of Pleistocene age and is composed of terrace deposits that consist of poorly consolidated gravel, sand, and silt. These deposits are found along the Sacramento River and adjacent tributaries and are up to 200 feet thick. Permeability of the Riverbank Formation is moderate to high, and yields of domestic wells are moderate. Groundwater occurs predominately under unconfined conditions.

Modesto Formation. The Modesto Formation terrace deposits are younger than the Riverbank Formation deposits and are composed of unconsolidated, slightly to unweathered gravel, sand, silt, and clay. Maximum thickness of the formation is approximately 200 feet. These deposits are seen along stream channels in the valley. Permeability of the Modesto Formation is variable. Well yields in the Modesto Formation are limited where areas of silt and clay predominate. Groundwater yields to domestic wells are higher in locations where gravels and sands predominate. Groundwater occurs under unconfined conditions.

Holocene Age Alluvium. Holocene age alluvium includes basin deposits and alluvium, which consist of surficial alluvial deposits and stream channel deposits.

Basin Deposits. Basin deposits consist of predominately silt and clay deposited in low-lying flood basin areas adjacent to major streams. Permeability of basin deposits is generally low, and groundwater occurs under unconfined conditions. Thickness of these deposits reach up to 200 feet near the center of the valley.

Alluvium. Holocene age alluvium of the basin occurs along the Sacramento, Feather, Yuba, Bear, American, and Cosumnes rivers. These deposits include unconsolidated, unweathered gravel, sand, silt, and clay from stream channel deposition, and dredged gravel deposited by past mining activities. Stream channel deposits contain a high fraction of gravel- and sand-sized material compared to basin deposits. Permeability of the alluvium is moderate to high, with sediment thickness up to 80 feet near the Sacramento River. Groundwater occurs under unconfined conditions.

Movement of Groundwater

Groundwater movement within the Sacramento Valley Groundwater Basin was evaluated based on groundwater elevation contours developed for the Sacramento Valley. The contours shown in Plates 3 and 4 were developed using March 1997 groundwater level data collected by DWR and local cooperators. Plate 3 shows the spring 1997 groundwater contours for the Sacramento Valley and the boundaries of the SRSC service areas. Plate 4 shows the spring 1997 contours with flow arrows indicating the direction of groundwater movement.

The flow arrows in Plate 4 illustrate that regional groundwater movement in the northern portion of the basin is inward from the basin edges, flowing toward the Sacramento River and southward along the valley axis. Plate 4 shows that Stony Creek (the boundary between the Corning and Colusa subbasins) is a major source of recharge for the northwestern portion of the groundwater basin and a major source of subsurface flow into the Sacramento River. The plate also suggests that the Thermalito Afterbay (near the northeast edge of the East Butte Subbasin) is also a major groundwater recharge source on the east side of the Sacramento Valley.

In addition, Plate 4 shows that the Sacramento River serves as the main groundwater drain for the northern basin north of Princeton. South of Princeton, the Sacramento River serves as a major source of groundwater recharge to several areas where the groundwater levels have dropped below the stage of the Sacramento River. Extensive groundwater development in the Sacramento metropolitan area has created a series of pronounced depressions in the groundwater surface to the east of the Sacramento River, along the southeast side of the basin. Two other smaller depressions in the groundwater surface, caused by extraction of groundwater for municipal and industrial use, are shown in the southwest portion of the basin, centered near Woodland and Davis. These pumping depressions divert and capture the natural direction of groundwater flow away from the Sacramento River and adjacent tributaries toward the center of the depression. By diverting and capturing the surrounding groundwater flow, these series of groundwater depressions effectively deplete the surface water system.

Local Groundwater Hydrology

Local Groundwater Hydrology

The following summarizes the local groundwater hydrology for individual Sacramento River Settlement Contractor service areas participating in the USBR's Basinwide Water Management Plan. Groundwater data with respect to groundwater basin and subbasin areas are presented by SRSC location. The SRSC service areas and the groundwater basin boundaries are shown in Plate 1. The only SRSC service area within the Redding basin is Anderson-Cottonwood Irrigation District. The ACID service area extends over several subbasins but primarily falls within the Anderson Subbasin. Discussion of the local groundwater hydrology for the Redding Groundwater Basin will focus on the Anderson Subbasin and ACID.

Within the Sacramento Valley Groundwater Basin, SRSC service areas are located in the Colusa, West Sutter, West Butte, and North American subbasins. Discussion of the local groundwater resources for the Sacramento Valley Groundwater Basin includes a hydrogeologic summary of those subbasins, with a detailed resource evaluation of the SRSC service areas.

Redding Groundwater Basin, Anderson Subbasin

The Anderson Subbasin is in the west-central portion of the Redding Groundwater Basin, as shown in Plate 1. The subbasin is bounded on the west by the Klamath Mountains, on the north by Clear Creek, on the east by the Sacramento River, and on the south by the North Fork Cottonwood Creek. The subbasin has a surface area of about 152 square miles and includes surface water and groundwater users.

West of the Sacramento River, fresh groundwater-bearing units in the Anderson Subbasin are unconsolidated to semi-consolidated continental deposits of late Tertiary to Quaternary age. Late Tertiary deposits consist of the Tehama Formation. Groundwater within the Tehama Formation is typically semi-confined to confined. Quaternary age deposits include the Modesto and Riverbank formations adjacent to Cottonwood and Dry creeks and Holocene alluvium. Groundwater within the Quaternary age deposits is typically unconfined to semi-confined.

The continental deposits thin toward the north and northwestern portions of the Anderson Subbasin and thicken to the south. Along the north and northwestern margins of the subbasin, the groundwater quality is generally poor. Many of the shallow domestic and irrigation wells fully penetrate the veneer of continental deposits and tap into the poor quality water of the underlying marine sedimentary rocks. Wells that do not fully penetrate the overlying continental deposits typically tap into the Nomlaki Tuff member of the lower Tehama Formation, which also tends to have poor water quality.

Anderson-Cottonwood Irrigation District

Anderson-Cottonwood Irrigation District (ACID) is situated along the eastern and southern margin of the Anderson Subbasin. Covering about 33,300 acres, the district forms a "U"-shaped area paralleling the Sacramento River and Cottonwood Creek. The district has a history of supplying Sacramento River surface water to users in its service area. Surface water use within ACID has an important role in recharging the groundwater basin and maintaining high, stable groundwater levels throughout the district. The ACID service area is shown in Plate 1.

Groundwater Levels. DWR currently monitors groundwater levels in six wells within the ACID. The ACID groundwater level monitoring grid consists of a mixture of domestic, industrial, irrigation, and unused wells. Table 2 lists the monitoring wells along with the annual fluctuation of groundwater levels during normal and drought years. Groundwater monitoring wells are shown in Plate 5.

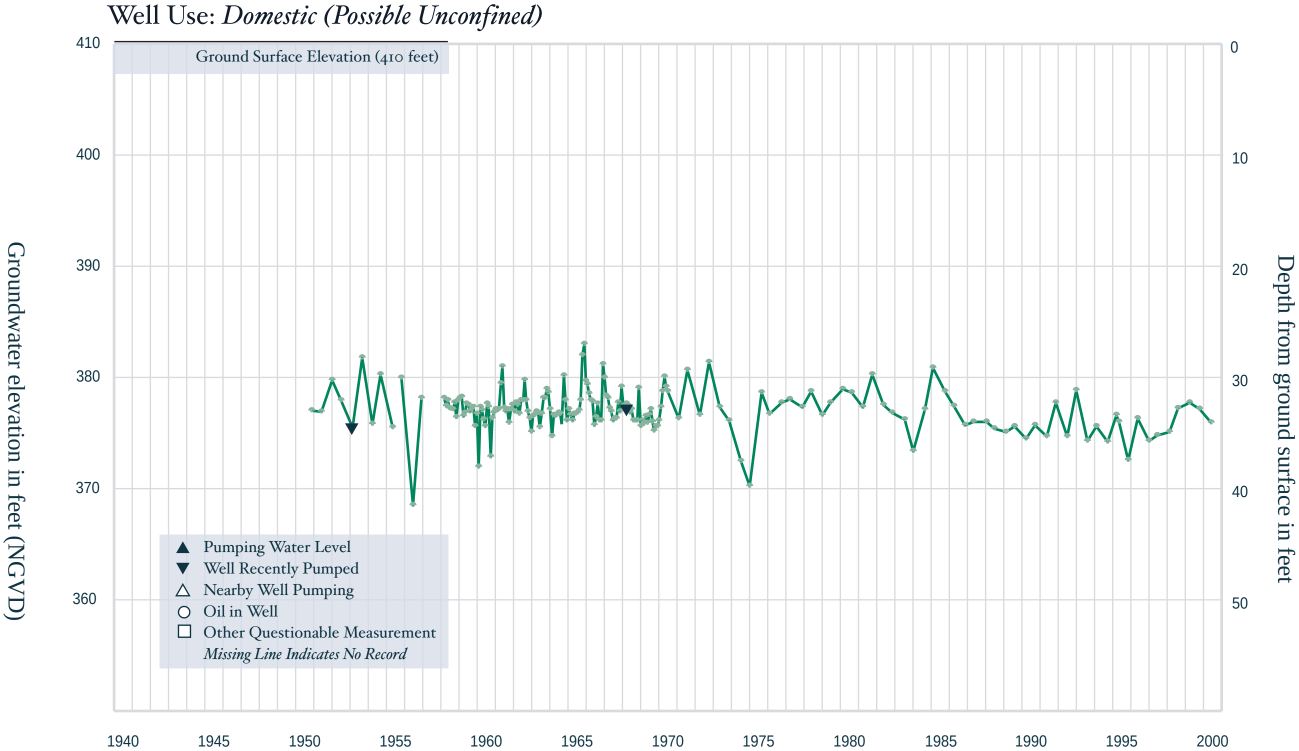
Historical groundwater levels for the ACID monitoring wells indicate that the annual fluctuation of groundwater levels in the unconfined portion of the aquifer system is between 2 and 4 feet during normal precipitation years and up to 10 feet during drought years. Annual fluctuation of groundwater levels in the confined or semi-confined portion of the aquifer system is about 2 to 4 feet during normal years, but up to 16 feet during drought years. Figure 2 is a hydrograph for State Well Number 29N/03W-06P01M, a shallow domestic well located to the north of Cottonwood Creek. The hydrograph shows a small to moderate change in seasonal groundwater levels, which is typical of wells constructed in the unconfined portion of the aquifer

Table 2
Annual fluctuation of groundwater levels within ACID

State Well Number	Well Use	Aquifer System	Annual Groundwater Fluctuation: Normal Years (feet)	Drought Years (feet)
29N/03W-06P01M	Domestic	Unconfined	2 – 4	4 – 6
29N/04W-02P01M	Idle*	Semi-confined	3 – 5	8 – 10
30N/03W-18F02M	Domestic	Unconfined	2 – 3	4 – 6
30N/04W-03Q01M	Domestic	Semi-confined	2 – 4	4 – 6
30N/04W-23G01M	Industrial	Confined	2 – 4	10 – 16
31N/04W-29R02M	Domestic	Unconfined	2 – 3	8 – 10

*Idle designation indicates a well that is currently non-operational

Figure 2
Hydrograph for State Well Number 29N/03W-06P01M in the Anderson Subbasin and southern ACID
Well Use: *Domestic (Possible Unconfined)*

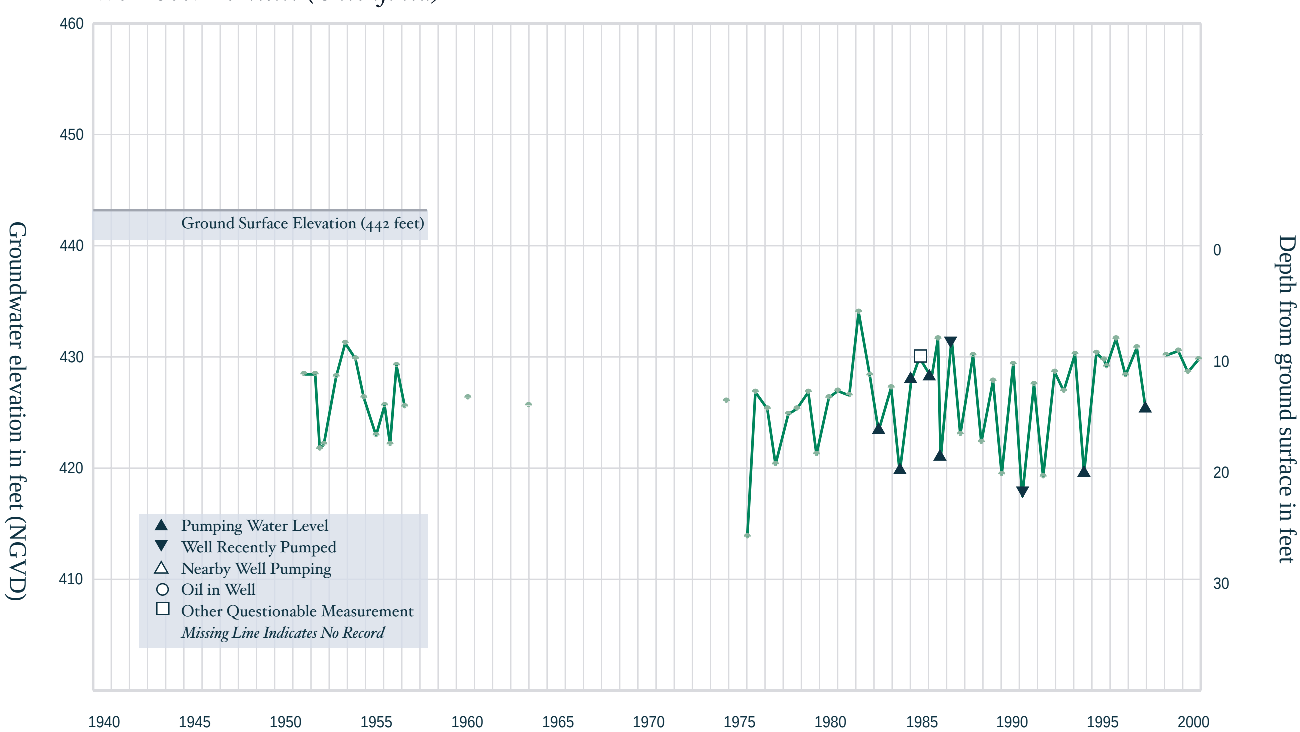


system. Groundwater levels in Figure 2 are representative of ACID wells that draw from the upper portion of the Tehama Formation.

Figure 3 is a hydrograph for State Well Number 31N/04W-29R02M, a domestic well constructed within the upper portion of the Tehama Formation. The well is located north of the Sacramento River, near the northeast corner of the district. The hydrograph shows a moderate fluctuation in seasonal groundwater levels and is typical of ACID wells constructed in the unconfined or semi-confined portion of the aquifer system.

Comparing spring-to-spring groundwater levels for the ACID hydrographs indicates that there has been little change in groundwater levels within ACID since the 1950s and 1960s. Most ACID wells show a decline in groundwater levels associated with the 1976-77 and

Figure 3
Hydrograph for State Well Number 31N/04W-29R02M in the Anderson Subbasin and northern ACID
Well Use: *Domestic (Unconfined)*



1987-92 droughts, followed by a recovery in groundwater levels to pre-drought conditions. Historical groundwater levels indicate that the basin fully recharges during years of normal or above-normal precipitation.

Groundwater Movement. In the northern portion of the district, groundwater flows generally to the south-southeast, toward the Sacramento River, at a gradient of about 10 feet per mile. Along Cottonwood Creek, in the southern portion of the district, groundwater flows at a gradient of approximately 15 feet per mile toward the creek and eastward toward the confluence of Cottonwood Creek and the Sacramento River. The gradient and direction of groundwater movement are shown in Plates 3 and 4.

Groundwater Extraction. The service area for ACID covers about 33,300 acres over portions of Shasta and Tehama counties. DWR conducted land and water use surveys for Shasta County in 1995 and for Tehama County in 1994. These surveys show that the net irrigated acreage within ACID was about 13,700 acres. Of the 13,700 net acres in production during 1994 and 1995, approximately 700 acres were irrigated with groundwater, 500 acres were irrigated with reclaimed groundwater, and about 12,500 acres were irrigated with surface water. The estimated total amount of groundwater applied is about 3,400 af. Of this amount, 1,700 af was extracted and applied to crops within the district and 1,700 af was reclaimed groundwater extracted for industrial purposes outside the district. Figure 4 shows general agricultural water use for the ACID service area based on historical land and water use data.

The water use areas delineated in Figure 4 show that about 13,400 acres within ACID have the potential to be serviced by surface water, 700 acres have the potential to be serviced by groundwater, and 500 acres have the potential to be serviced by reclaimed groundwater. Figure 4 also shows that fewer than 50 acres have the potential to be serviced by a mixed water source, and approximately 18,700 acres within the ACID service area are non-irrigated.

Well Yield. Well yield data associated with irrigation, industrial, and municipal wells were collected from Well Completion Reports filed with DWR. Of the 99 wells examined within the ACID area, nine of the completion reports listed well yield data. Seven of the nine wells had a reported yield of 300 gpm or less. The remaining two wells had reported yields of more than 1,800 gpm. The small number and limited distribution of wells reporting well yield data within the ACID area prevents adequate characterization of well yield by statistical methods.

Well Depth. Well depth and well use data for the ACID area were collected from Well Completion Reports filed with DWR. A summary of the minimum, maximum, and average well depth, listed by well use, is shown in Table 3.

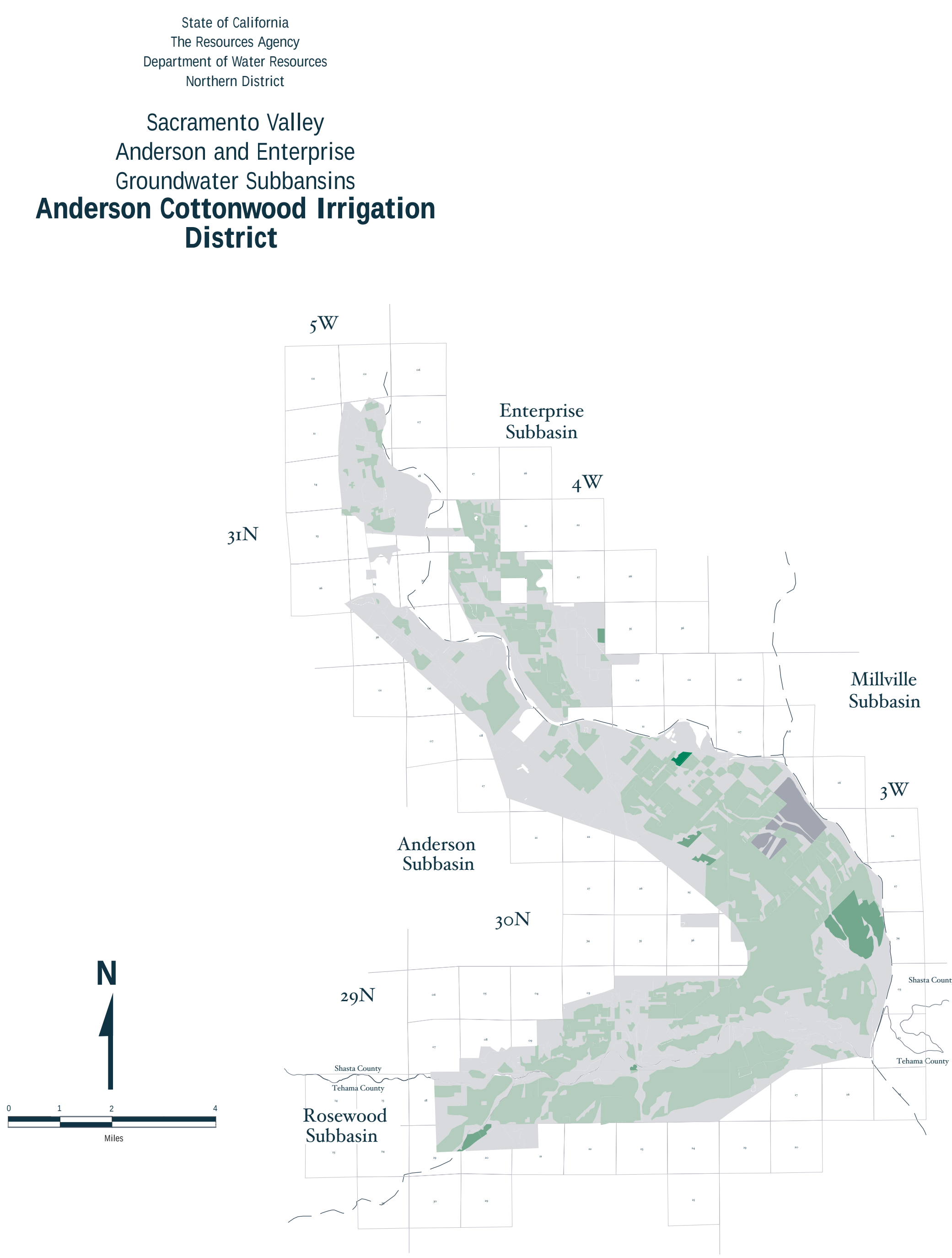
Table 3
Well depths in ACID listed according to well use

Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	1,718	20	683	95
Industrial	29	40	465	216
Municipal	21	51	520	264
Irrigation	49	32	553	223
Other	50	30	680	212

Most wells within ACID are drilled for domestic use. The average depth of the domestic wells within ACID is about 95 feet. The high-yield production wells, drilled for irrigation, municipal, and industrial use, tend to be deeper than the low-yielding wells drilled for domestic use. The average depth of irrigation, municipal, and industrial wells ranges from about 200 to 260 feet.

The well depth data were further analyzed using cumulative frequency distribution and histograms of well depth for domestic and irrigation wells. Figure 5 shows the cumulative frequency distribution of well depth for domestic wells in the ACID service area. A total of 1,718 domestic wells were analyzed in terms of cumulative frequency distribution with respect to well depth. The depth of domestic wells ranged from 20 to 683 feet. (Seven wells with depths greater than 500 feet are not shown on Figure 5 due to scaling of the graph.)

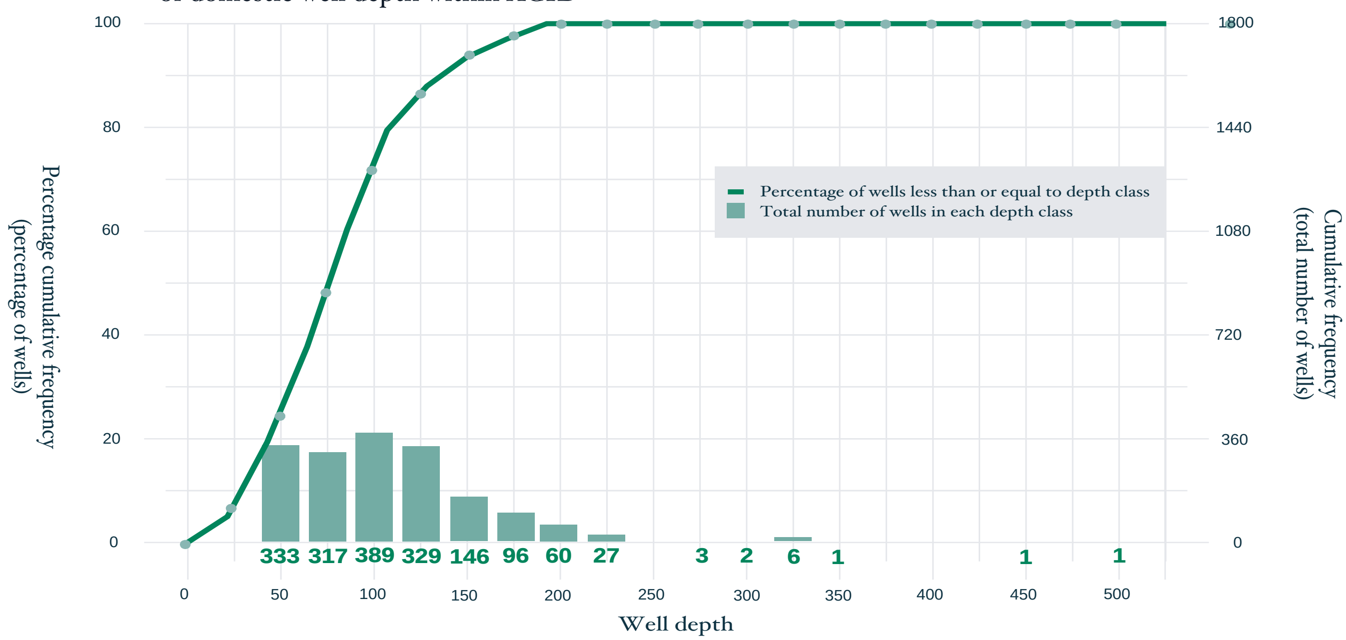
Figure 4
Water use map for ACID



- Potential Areas Irrigated with Surface Water (13,400 acres)
- Potential Areas Irrigated with Groundwater (700 acres)
- Potential Areas Irrigated with Surface Water and Groundwater (<50 acres)
- Potential Non-Irrigated Areas (18,700 acres)
- Potential Acreage Irrigated with Reclaimed Groundwater (500 acres)

Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.

Figure 5
Cumulative frequency distribution and histogram of domestic well depth within ACID



The histogram bars in Figure 5 shows the total number of wells associated with each 25-foot class interval. The distribution of data of domestic wells indicates that average well depth is shallower than the most frequently occurring well depth.

The cumulative frequency curve of domestic well depth data for ACID shows that:

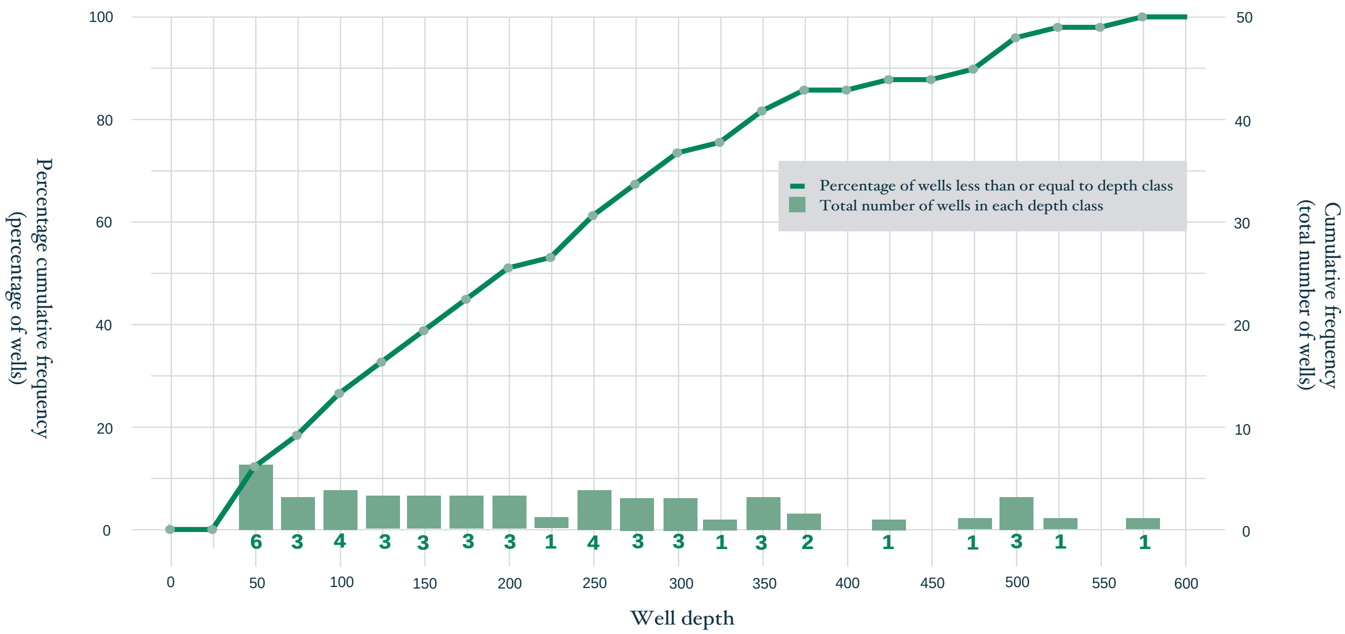
50 percent of the domestic wells are installed to a depth of about 90 feet or less,

10 percent of the wells are installed to a depth of about 36 feet or less.

Figure 6 shows the cumulative frequency distribution of well depth data for irrigation wells in the ACID service area. A total of 49 irrigation wells were analyzed in terms of cumulative frequency distribution with respect to well depth. The irrigation wells range in depth from 32 to 553 feet.

The distribution of irrigation well depth data is highly asymmetrical, showing no resemblance to a normal distribution. The asymmetrical distribution of the irrigation well depth data indicates that there is a

Figure 6
Cumulative frequency distribution and histogram of irrigation well depth within ACID



wide range of irrigation well depths within ACID and that no dominant well depth preference exists.

The cumulative frequency curve of well depth data for ACID irrigation wells shows that:

50 percent of the irrigation wells are installed to a depth of about 190 feet or less,

10 percent of the irrigation wells are installed to a depth of about 45 feet or less.

Specific Capacity. No specific capacity data from published sources are available for the Redding Groundwater Basin.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the ACID area is about 30 feet. Estimates of groundwater storage capacity beneath ACID assume a maximum aquifer saturation from a uniform depth of 30 feet to the base of fresh water at 2,500 feet, a service area of about 33,300 acres, and a specific yield of 8.5 percent (Pierce 1983). Based on these assumptions, the estimated groundwater storage capacity beneath

ACID is 6,990 taf. The methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

Groundwater in Storage. Table 4 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

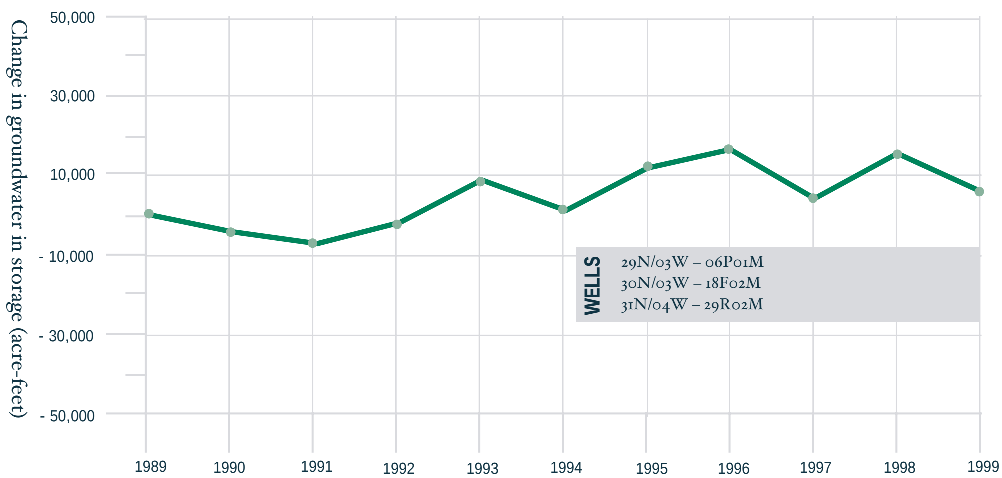
Table 4
Estimated amount of groundwater in storage within ACID

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	30 feet	6,990 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	480 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	190 feet	450 taf
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	45 feet	42 taf

Changes in Groundwater in Storage, 1989-99. The estimated spring-to-spring change in groundwater in storage for the ACID service area is illustrated in Figure 7. The three ACID monitoring wells used to estimate changes in groundwater in storage are also listed in Figure 7. Their locations are shown in Plate 5. These wells are distributed fairly evenly within the ACID service area.

Spring-to-spring groundwater in storage dropped below the 1989 baseline storage level during the drought of the early 1990s and then recovered through the late 1990s. The amount of groundwater in storage during the spring of 1999 was about

Figure 7
Changes in groundwater in storage in ACID, 1989-99



5,000 af greater than during the spring of 1989. The methodology used to estimate changes in groundwater in storage is discussed in Section 1.

Conjunctive Management Potential. Based on available data, it appears that there is potential for limited conjunctive management in the ACID service area. However, the project configuration and yield can not be quantified at this time because additional investigations are needed to determine the best approach to conjunctive use operations, including methods of groundwater recharge and recovery of stored groundwater. Additional studies are also needed to ensure compliance with local groundwater management plans and ordinances.

The use of in-lieu methods has the best potential for aquifer recharge within ACID , according to existing data. In-lieu recharge would require construction of conveyance facilities to deliver surface water to areas currently irrigated by groundwater. Recovery of stored groundwater could best be accomplished by substituting groundwater for surface water by using existing irrigation wells, or using new wells installed specifically for groundwater recovery.

Sacramento Valley Groundwater Basin, Colusa Subbasin

The Colusa Subbasin is the largest single subbasin in the Sacramento Valley Groundwater Basin. The subbasin is along the west side of the basin and is bordered on the west by the Coast Ranges, on the north by Stony Creek, on the east by the Sacramento River, and on the south by Cache Creek. Sacramento River Settlement Contractors within the Colusa Subbasin are shown in Plate 1 and include:
Glenn-Colusa Irrigation District
Provident Irrigation District
Princeton-Cordora-Glenn Irrigation District
Maxwell Irrigation District
Reclamation District 108

The Colusa Subbasin aquifer system is composed of continental deposits of late Tertiary to Quaternary age. The Quaternary age deposits include alluvial and flood basin deposits, and deposits of the Modesto and Riverbank formations. The Tertiary deposits include the Tehama Formation and the Tuscan Formation. The main water-bearing formation in the Colusa Subbasin is the Tehama Formation.

The Tehama Formation is different in the northern and southern portions of the subbasin. In the northern subbasin, the formation contains extensive deposits of interbedded gravel from the ancestral Stony Creek. These deposits are informally referred to as the Stony Creek Member of the Tehama Formation. The Stony Creek Member of the Tehama Formation is typically productive, yielding a large quantity of water to wells. In the southern Colusa Subbasin, the Tehama Formation is less productive, although isolated zones of high production do occur.

The Tuscan Formation is an important water-bearing unit in the northeastern portion of the Colusa Subbasin, although at present it is not significantly used. The Tuscan Formation enters the Sacramento Valley along the eastern margin of the West Butte Subbasin. Extending 15 miles westward, the formation dips beneath the Colusa Subbasin as it interfingers with the Tehama Formation at depths between 300 and 1,000 feet. Estimates of the depth to the Tuscan Formation in this area are based on preliminary data from ongoing DWR investigations.

Natural recharge consists of infiltration from precipitation and surface water and from groundwater underflow from the western and eastern margins of the subbasin. Significant recharge also occurs from the application and percolation of irrigation water. Seasonal fluctuations in the groundwater level are minimal and generally less than about 10 feet (DWR 1996).

Glenn-Colusa Irrigation District

Glenn-Colusa Irrigation District (GCID) is in the north-central portion of the Colusa Subbasin. The GCID service area covers about 175,000 acres, extending north to south from Willows to Maxwell. Glenn-Colusa Irrigation District has a history of supplying Sacramento River water to members in its service area. Recharge from surface water irrigation and limited groundwater use have maintained the aquifer system at nearly full for many years. Occasional deficiencies in surface water supplies have led GCID to supplement surface water with groundwater. The GCID service area is shown in Plate 1.

Groundwater Levels. DWR monitors groundwater levels in 12 wells within the GCID service area. The GCID groundwater level-monitoring grid consists of a mixture of domestic, irrigation, and industrial wells, and several dedicated observation wells. Table 5 lists the GCID wells that are currently being monitored, along with the annual fluctuation of groundwater levels during normal and drought years. Groundwater monitoring wells are shown in Plate 5.

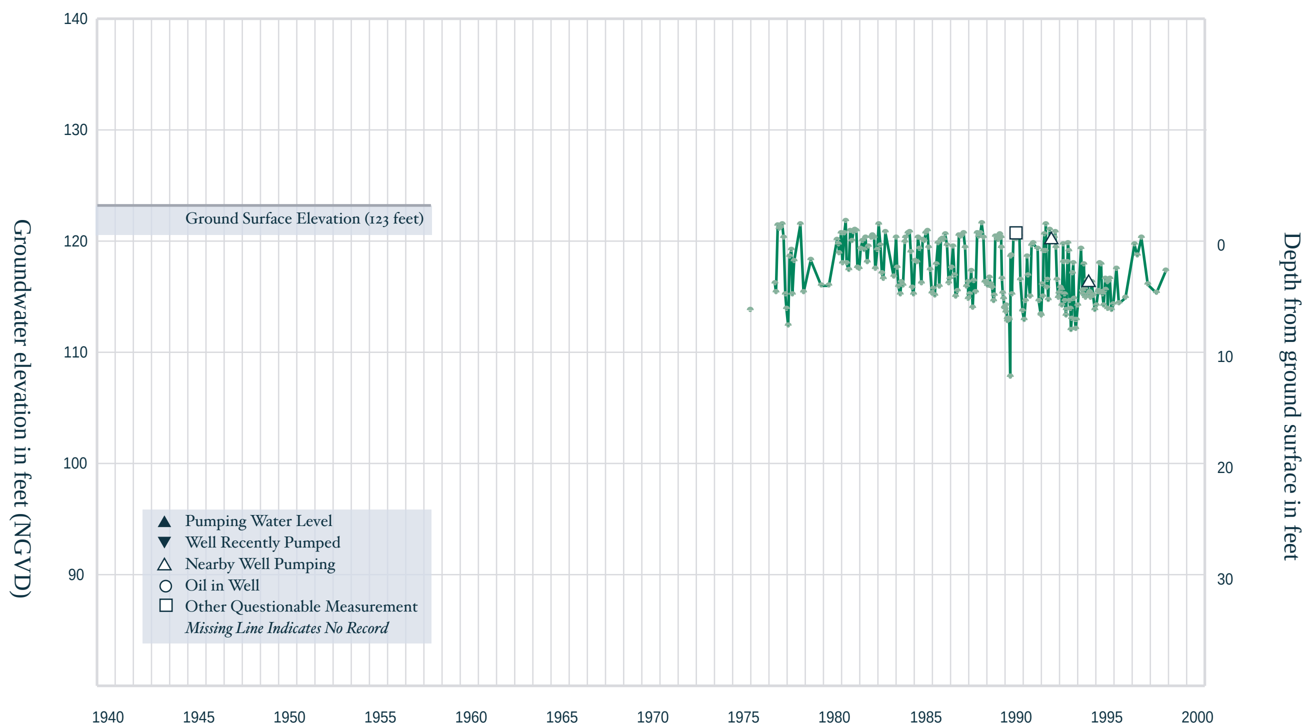
Historical groundwater level data for GCID monitoring wells indicate that the annual fluctuation of groundwater levels in the unconfined portion of the aquifer system averages between 2 and 4 feet during normal precipitation years, and up to 12 feet during drought years. Annual fluctuation of groundwater levels in the confined or semi-confined portion of the aquifer system is typically larger, with an average of 4 to 8 feet during normal years, and up to 30 feet during drought years. Wells located near recharge sources typically show less of an annual change in groundwater levels.

Figure 8 is a hydrograph for State Well Number 20N/02W-11A01M, a multi-completion observation well installed by DWR in 1977. This

Table 5
Annual fluctuation of groundwater levels within GCID

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Drought Years (feet)
15N/02W-19E01M	Irrigation	Confined	6 – 9	10 – 14
15N/03W-01N01M	Industrial	Confined	10 –20	15 – 25
15N/03W-28A01M	Industrial	Unconfined	1 – 2	2 – 4
16N/03W-07Q01M	Domestic	Unconfined	1 – 2	2 – 4
16N/03W-35N02M	Domestic	Confined	4 – 5	8 – 10
19N/02W-29Q01M	Domestic	Confined	3 – 4	8 – 10
19N/03W-26P01M	Domestic	Confined	2 – 4	6 – 8
20N/02W-02J01M	Domestic	Unconfined	2 – 4	4 – 6
20N/02W-11A01M	Observation	Unconfined	5 – 6	8 – 12
20N/02W-11A02M	Observation	Confined	4 – 8	6 – 26
20N/02W-11A03M	Observation	Confined	6 – 14	12 – 30
20N/02W-13G01M	Domestic	Composite	2 – 3	3 – 6

Figure 8
Hydrograph for State Well Number 20N/02W-11A01M
in the Colusa Subbasin and northeastern GCID
Well Use: *Observation (Probable Unconfined)*



well monitors the upper aquifer system within the Stony Creek Member of the Tehama Formation, and is representative of the unconfined conditions in the northeast corner of GCID. Groundwater levels in this well were monitored monthly until the mid-1990s, when the monitoring changed to quarterly.

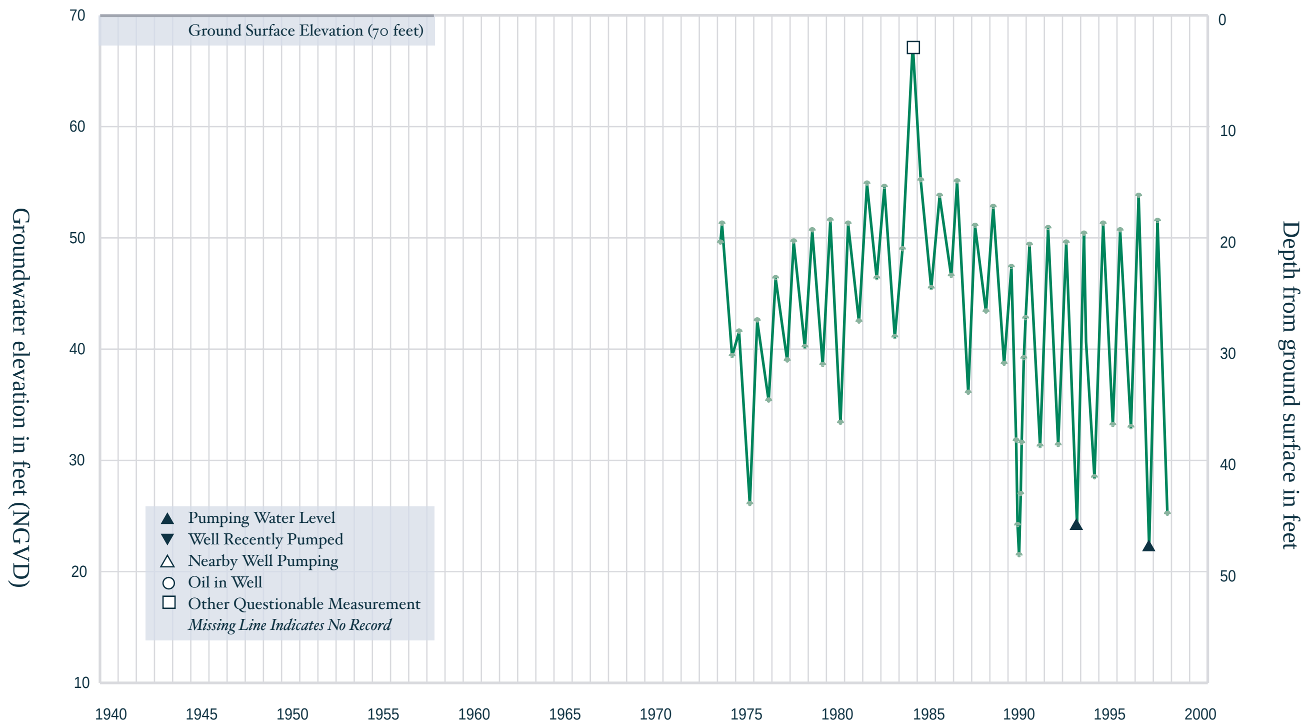
In many areas of the Sacramento Valley, the natural trend for groundwater levels associated with the shallow aquifer system is to peak in the spring, decline with increasing extraction during the dry summer months, then slowly recover through the fall and winter as temperatures cool and precipitation becomes more frequent. In Figure 8, this trend is altered because of flood irrigation with surface water, causing artificially high water levels to occur during summer months.

Figure 9 is a hydrograph for State Well Number 15N/03W-01N01M, an industrial well constructed within the deeper portion of the Tehama Formation. The hydrograph in Figure 9 is representative of groundwater levels from the confined portion of the aquifer system in the southern portion of GCID, near Williams.

Figure 9 shows an annual fluctuation characterized by high groundwater levels during the spring and low groundwater levels during the fall. This trend in groundwater level fluctuation is typical of deeper aquifers, which respond quickly to extraction and less quickly to recharge from flood irrigation with surface water.

Of the 12 monitoring wells in the GCID area, eight have groundwater level records dating to the mid-1970s. Of the remaining four wells, two have groundwater level records dating to the early 1950s, and two have records dating to the early 1940s. Comparing spring-to-spring groundwater levels for the existing monitoring wells in the GCID service area indicates that there has been little change in groundwater levels since the 1940s and 1950s. Most of the GCID monitoring wells show a decline in groundwater levels associated with the 1976-77 and 1987-92 droughts, followed by a recovery in groundwater levels to pre-drought conditions. Historical groundwater levels indicate that under the current hydrology, the basin fully recharges during years of normal precipitation.

Figure 9
Hydrograph for State Well Number 15N/03W-01N01M
in the Colusa Subbasin and the southern GCID
Well Use: *Industrial (Definite Confined)*



Groundwater Movement. In the northern portion of GCID, between Artois and Glenn, groundwater movement is generally to the southeast, toward the Sacramento River, at a gradient of about 6.5 feet per mile. In the middle of the district, near Maxwell, the flow changes to a more easterly direction with a steeper gradient of about 10.3 feet per mile. At the southern end of the district, near Williams, groundwater flows east to slightly northeast, toward the Colusa Basin and the Sacramento River. The groundwater gradient along the southwestern GCID boundary begins at about 10 feet per mile, then flattens to about 7.5 feet per mile at the southeastern edge of the district. The direction and gradient are shown in Plates 3 and 4.

Groundwater Extraction. The service area for GCID covers about 175,000 acres over portions of Glenn and Colusa Counties. DWR conducted land use surveys for Glenn and Colusa Counties in 1993. Those surveys show that the net irrigated acreage for GCID was about 125,000 acres. Of the 125,000 net acres in production during 1993, approximately 4,200 acres were irrigated with groundwater, and about 120,800 acres were irrigated with surface water. The estimated amount of groundwater applied to the 4,200 acres was 17,000 acre-feet. Figure 10 shows general agricultural water use for the GCID service area developed from historical land and water use data. Land within the Sacramento National Wildlife Refuge Complex was not included in the water use acreage estimates for GCID.

Water use areas delineated in Figure 10 show that about 135,000 acres within GCID have the potential to be serviced by surface water, 3,500 acres have the potential to be serviced by groundwater, and 1,700 acres have the potential to be serviced by a mixed water source.

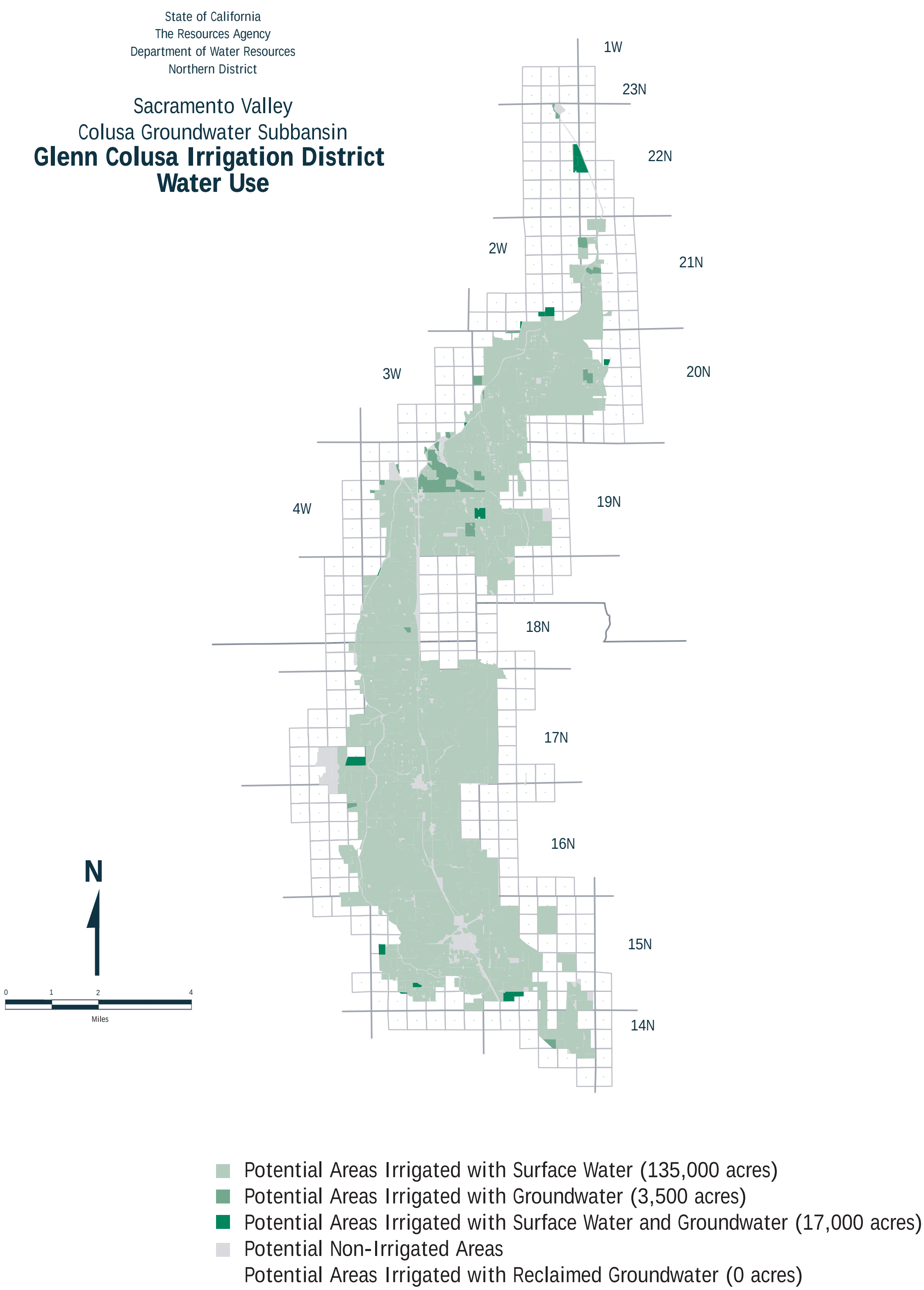
GCID's Sacramento River diversion has been cut back during drought years and, since 1993, during some summer months because a minimum amount of water must be left in the river to sustain the aquatic habitat for fishery concerns. In other years, GCID has participated in voluntary commingling agreements and groundwater purchase agreements to augment water supplies. In both situations, the amount of groundwater extracted annually is increased to offset reductions in surface water supply. The additional groundwater supply comes from district wells and more than 160 privately-owned wells within the district. In 1992 and 1994, GCID's groundwater extraction increased to 88,000 and 95,000 af, respectively, to offset surface water supply reductions. Most of the increased groundwater extraction occurred in the northern part of the district.

Well Yield. In 1961, USGS compiled utility pump test records and summarized the average well yield data for irrigation wells in the Orland-Willows and Williams regions. These regions cover much of the GCID service area and extend from the Tehama-Glenn to the Colusa-Yolo county lines. Well yield data from this investigation are summarized in Table 6.

Table 6
Well yield summary for GCID

	Orland-Willows	Williams
Number of Wells	238	103
Average Depth	210 ft	494 ft
Average Yield	1,030 gpm	620 gpm

Figure 10
Water use map for GCID



Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

Table 6 shows that irrigation wells in the northern GCID area are generally shallower and more productive than irrigation wells in the southern portion of the district, near Williams. The higher yields associated with shallow irrigation wells in the northern GCID area are attributed to high productivity from the Stony Creek Member of the Tehama Formation.

There are 895 Well Completion Reports filed with DWR for the GCID area. Only 27 reports list well yield data. Of the 27 wells, 45 percent have a reported yield of less than 1,200 gpm, 22 percent have a yield between 1,200 and 3,000 gpm, and 33 percent have a reported yield greater than 3,000 gpm.

Well Depth. Well depth and well use data for the GCID area were collected from Well Completion Reports filed with DWR. A summary of the minimum, maximum, and average well depth, listed by well use, is shown in Table 7.

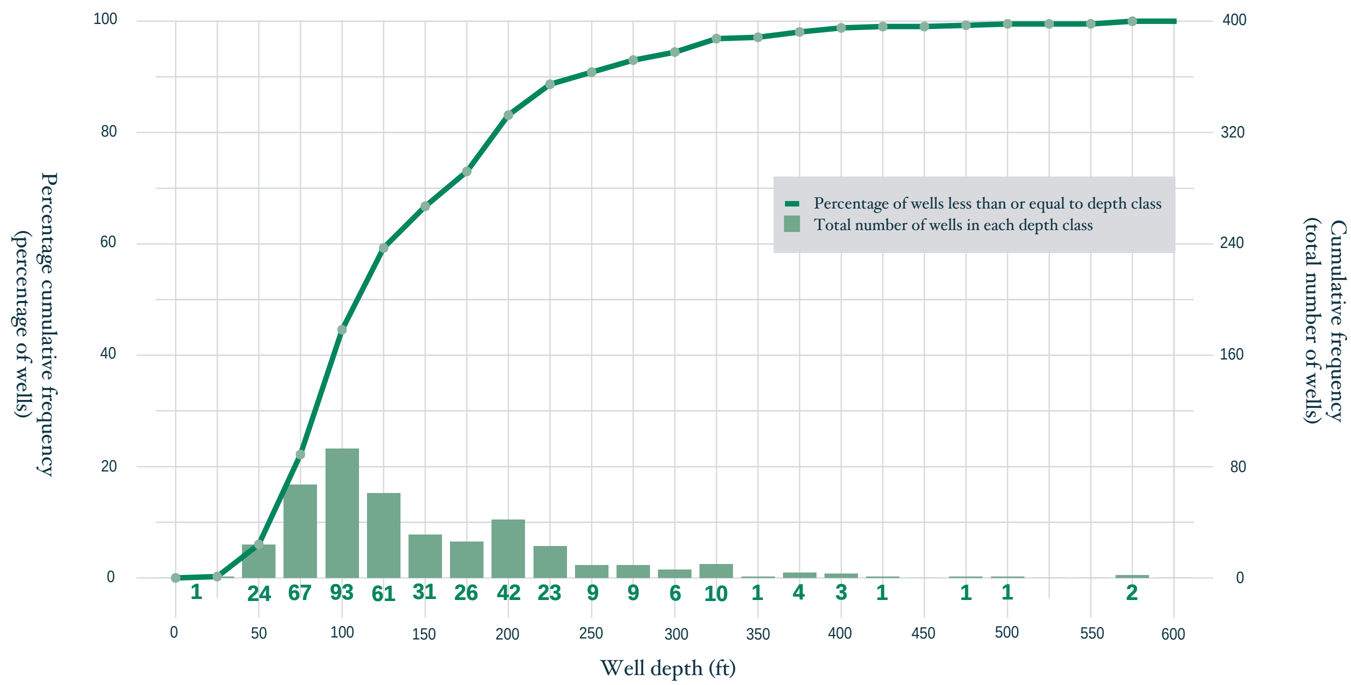
Table 7
Well depths in GCID listed according to well use

Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	414	20	570	136
Industrial	17	44	634	317
Municipal	14	220	748	502
Irrigation	301	50	955	285
Other	148	10	110	163

Table 7 shows that about 46 percent of the wells in GCID are drilled for domestic use, and 33 percent are drilled for irrigation. Municipal and industrial use wells account for only 3.5 percent of the wells. The average depth of the domestic wells within GCID is about 136 feet, while the higher-producing irrigation, industrial, and municipal wells tend to be significantly deeper, with average depths of 285 feet for irrigation, 317 feet for industrial, and 502 feet for municipal wells.

The well depth data were further analyzed using cumulative frequency distribution and histograms of domestic and irrigation well depths. Figure 11 is a cumulative frequency distribution and histogram for the depth of domestic wells in the GCID service area. A total of 415 domestic wells were used in the analysis. The domestic wells ranged in depth from 20 to 570 feet.

Figure 11
Cumulative frequency distribution and histogram of domestic well depth within GCID



The histogram in Figure 11 shows the number of wells associated with each 25-foot depth class interval. The distribution of domestic well data indicates that the most frequently occurring well depth, or the depth class interval with the greatest number of wells, is shallower than the average well depth.

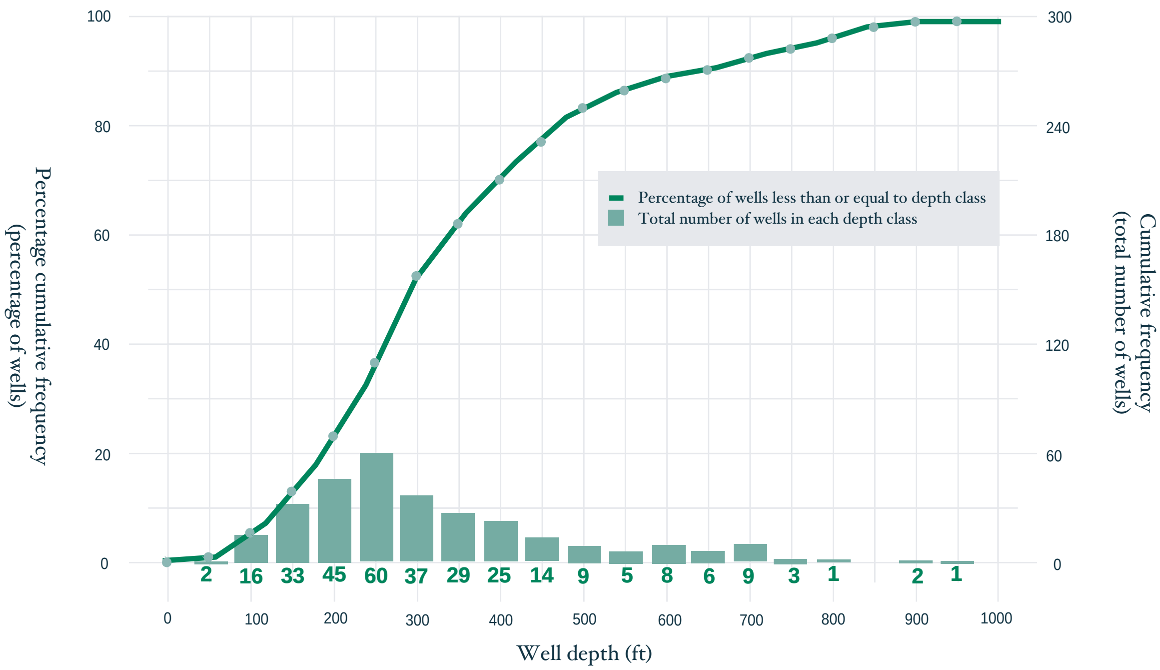
The cumulative frequency curve of domestic well depth data for GCID shows that:

50 percent of the domestic wells are installed to a depth of about 110 feet or less,

10 percent of the wells are installed to a depth of about 55 feet or less.

Figure 12 shows the cumulative frequency distribution and histogram for the depth of irrigation wells in the GCID service area. A total of 308 irrigation wells were used in the analysis. The irrigation wells ranged in depth from 50 to 955 feet.

Figure 12
Cumulative frequency distribution and histogram of irrigation well depth within GCID



The histogram in Figure 12 shows that the distribution of irrigation well depth data is skewed slightly to the right, toward deeper well depths. The distribution of the irrigation well data indicates that average well depth is deeper than the most frequently occurring well depth.

The cumulative frequency curve of irrigation well depth data for GCID shows that:

50 percent of the irrigation wells are installed to a depth of about 250 feet or less,

10 percent of the irrigation wells are installed to a depth of about 110 feet or less.

Specific Capacity. In 1961, USGS compiled utility pump test records and reported an average specific capacity of 76 and 33 gpm/ft for wells near the Orland-Willows and Williams regions, respectively. These regions extend from the Tehama-Glenn to the Colusa-Yolo county lines, and cover much of the GCID service area.

In 1989, GCID drilled a 16-inch, 720-foot-deep test production well near mile 13 of the GCID Main Canal. The well was drilled to assess the effects of pumping the mid-to-lower portion of the aquifer system (CH2M Hill 1989). Step-drawdown and long-term, constant discharge aquifer tests were conducted using the test production well. The step-drawdown test consisted of pumping the well for two hours at rates of 1,250, 1,900, 2,500, and 3,500 gpm. The long-term constant discharge test consisted of extracting groundwater at about 3,100 gpm for 33 days. The results from the test, shown in Table 8, indicate that the specific capacity decreased as the rate and duration of extraction increased. The specific capacity after 33 days of pumping at 3,100 gpm was calculated at about 91 gpm/ft.

Table 8
Specific capacity data from GCID test production well

	Step-Drawdown Test Results	
Pumping Rate(gpm)	Drawdown(ft)	Specific Capacity(gpm/ft)
1,250	6.5	192 @ 2 hrs.
1,900	13	146 @ 2 hrs.
2,500	18	138 @ 2 hrs.
3,500	28	125 @ 2 hrs.
	Constant Discharge Test Results	
3,100	34	91 @ 33 days.

The GCID service area covers about 175,000 acres. Current estimates indicate that in the northern portion of GCID, the average depth to groundwater is only 5 to 10 feet and that the aquifer system is at maximum groundwater storage capacity. The average depth of water at about 10 to 20 feet is slightly greater in the southern portion of GCID. Estimates of groundwater storage capacity beneath GCID assume uniform aquifer saturation from a depth of 10 feet to the base of fresh water at about 1,400 feet. The average specific yield for the upper 200 feet of the aquifer in the GCID area, determined by USGS, ranges from 10 to 12 percent for areas north of

Princeton and about 5 percent for the southern GCID area. The average specific yield for the GCID service area is estimated at 7 percent. Based on these assumptions, the estimated groundwater storage capacity beneath GCID is 17,000 taf. The methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

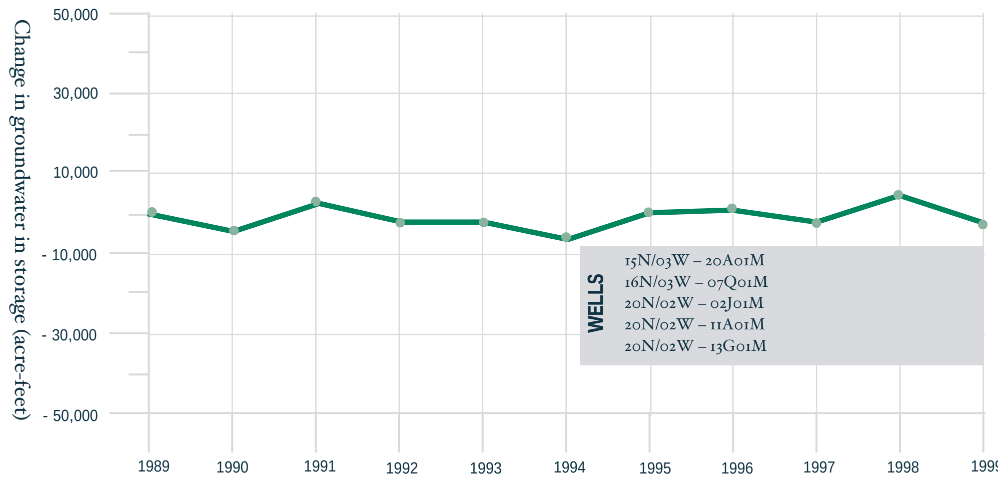
Groundwater in Storage. Table 9 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

Table 9
Estimated amount of groundwater in storage in GCID

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	10 feet	17,000 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	2,300 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	250 feet	2,900 taf
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	110 feet	1,200 taf

Changes in Groundwater in Storage, 1989-99. The estimated spring-to-spring change in groundwater in storage for the GCID area is illustrated in Figure 13. The five GCID monitoring wells used to estimate changes in groundwater in storage are listed in Figure 13. Their locations are shown in Plate 5. Three of these wells are located in the northern portion of GCID, and the other two are located in the southern portion of GCID. The estimates of changes in storage shown in Figure 13 represent an average change for these areas only.

Figure 13
Changes in groundwater in storage in GCID, 1989-99



The spring-to-spring groundwater in storage dropped slightly below the 1989 baseline storage level during the drought years of 1991 through 1994. Figure 13 shows that the amount of groundwater in storage beneath GCID has changed very little over the last 10 years. The methodology used to estimate changes in groundwater in storage is discussed in Chapter 1.

Conjunctive Management Potential. Of all the SRSC service areas in the Sacramento Valley, GCID probably has the highest potential for developing water supplies through conjunctive management. Existing data indicate that direct recharge and in-lieu recharge methods can be effective. In GCID, in-lieu recharge is currently practiced, and much of the infrastructure necessary to operate a conjunctive management project is in place . Additional studies are still needed to determine the optimum approach to conjunctive use operations, including methods and strategies of groundwater recharge and recovery of stored groundwater. Additional studies are also needed to ensure compliance with the local groundwater management plans and local ordinances.

Provident Irrigation District

The Provident Irrigation District (PID) is in the northeastern portion of the Colusa Subbasin, between Glenn Colusa Irrigation District and Princeton-Codora-Glenn Irrigation District. PID is divided into north and south service areas, covering about 15,800 acres. The northern service area extends south from Sidds Landing, about 7 miles east of Willows to County Road 59. The southern service area begins at County Road 61 and continues south, past the Glenn-Colusa county line, to the confluence of Willow Creek and the Colusa Drain. Much of the 2-mile gap between PID's north and south service area is part of the Glenn-Colusa Irrigation District. The PID service area is shown in Plate 1.

The primary sources of irrigation water for PID are surface water from the Sacramento River and drain water from adjacent districts. PID has been diverting Sacramento River water since 1906 (Borcalli & Associates 1995). However, PID owns several irrigation wells and has supplemented its surface water supply with groundwater during drought. Use of surface water within the district has maintained the aquifer at or near full capacity for decades.

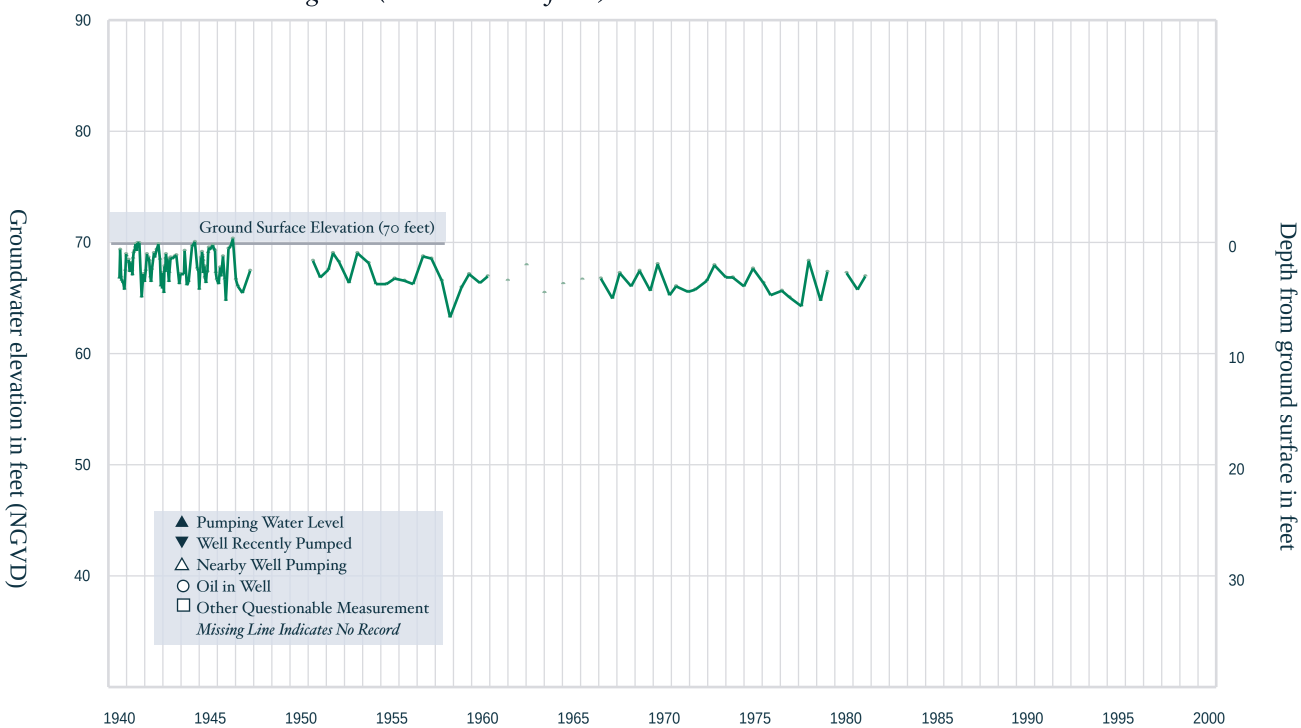
Groundwater Levels. DWR has groundwater level data for three wells within PID. The PID groundwater level-monitoring grid consists of domestic, irrigation, and observation wells. The period of record for these wells extends from the 1940s and 1960s to the early 1990s. Three monitoring wells in the PID area were dropped in the early 1990s, when monitoring indicated questionable measurements because of a borehole cave-in, obstructions in the wells, or leaky casings. Monitoring wells State Well Number 18N/02W-15N01M and State Well Number 19N/02W-09A01M were dropped before the 1991 drought, and State Well Number 19N/02W-23Q02M was dropped in 1992. Table 10 lists the PID monitoring wells, along with the annual fluctuation of groundwater levels during normal and drought years.

Table 10
Annual fluctuation of groundwater levels within PID

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Annual GW Fluctuation: Drought Years (feet)
18N/02W-15N01M	Idle* Irrigation	Unconfined	2 – 3	3 – 5
19N/02W-23Q02M	Domestic	Semi-confined	3 – 4	5 – 10
19N/02W-09A01M	Observation	Unconfined	1 – 2	2 – 4

*Idle designation indicates a well that is currently non-operational

Figure 14
Hydrograph for State Well Number 18N/02W-15N01M
in the Colusa Subbasin and southern PID
Well Use: *Idle Irrigation (Probable Unconfined)*



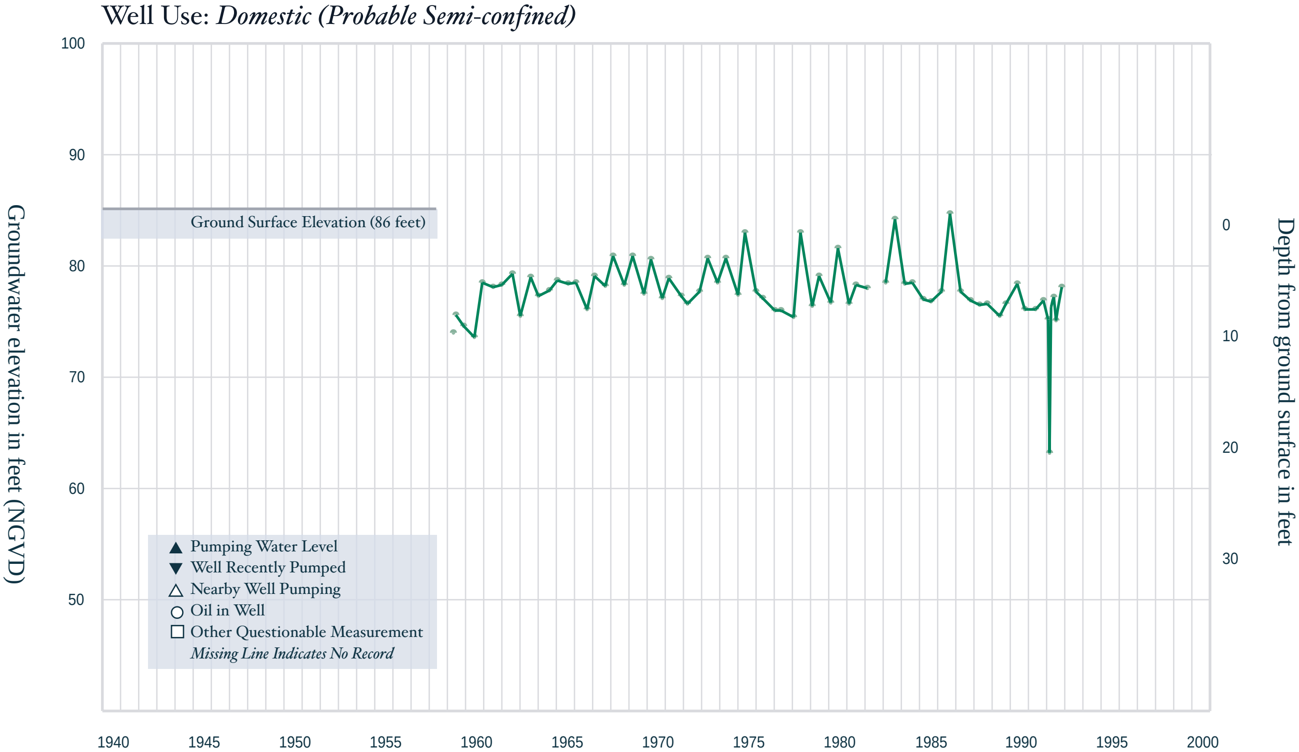
Groundwater level data for the PID monitoring wells indicate that the annual fluctuation of groundwater levels in the unconfined portion of the aquifer system averages between 2 and 3 feet during normal precipitation years, and up to 5 feet during drought years. Based on State Well Number 19N/02W-23Q02M, the annual fluctuation of groundwater levels in the semi-confined portion of the aquifer system appears slightly larger, with an average of 3 to 4 feet during normal years and up to 10 feet during drought years. Regional estimates of aquifer response to drought conditions are not possible because of the limited number of monitoring wells and the limited duration of record.

Figure 14 is a hydrograph for State Well Number 18N/02W-15N01M, a very shallow idle irrigation well located in the southern portion of PID. The hydrograph shows minor changes in seasonal groundwater levels and is indicative of wells constructed in the unconfined portion of the aquifer system.

Figure 15 is a hydrograph for State Well Number 19N/02W-23Q02M, a domestic well constructed within the upper portion of the Tehama Formation. The well is located within the central portion of PID, along the southern edge of the northern service area.

Comparing spring-to-spring groundwater levels for the three PID wells indicates that there has been little change in groundwater levels within PID since the 1940s. The two shallow wells, which draw from

Figure 15
Hydrograph for State Well Number 19N/02W-23Q02M
in the Colusa Subbasin and central PID
Well Use: *Domestic (Probable Semi-confined)*



the unconfined portion of the aquifer, show little decline in groundwater levels associated with the 1976-77 drought. No groundwater levels were measured during the 1990-1994 drought. State Well Number 19N/02W-23Q02M, which draws from the semi-confined portion of the aquifer, shows a reduction in the recovery of spring groundwater levels during the 1976-77 drought and the early part of the 1987-92 drought. Historical groundwater level data from the three wells indicate that the basin fully recharges during years of normal or above-normal precipitation.

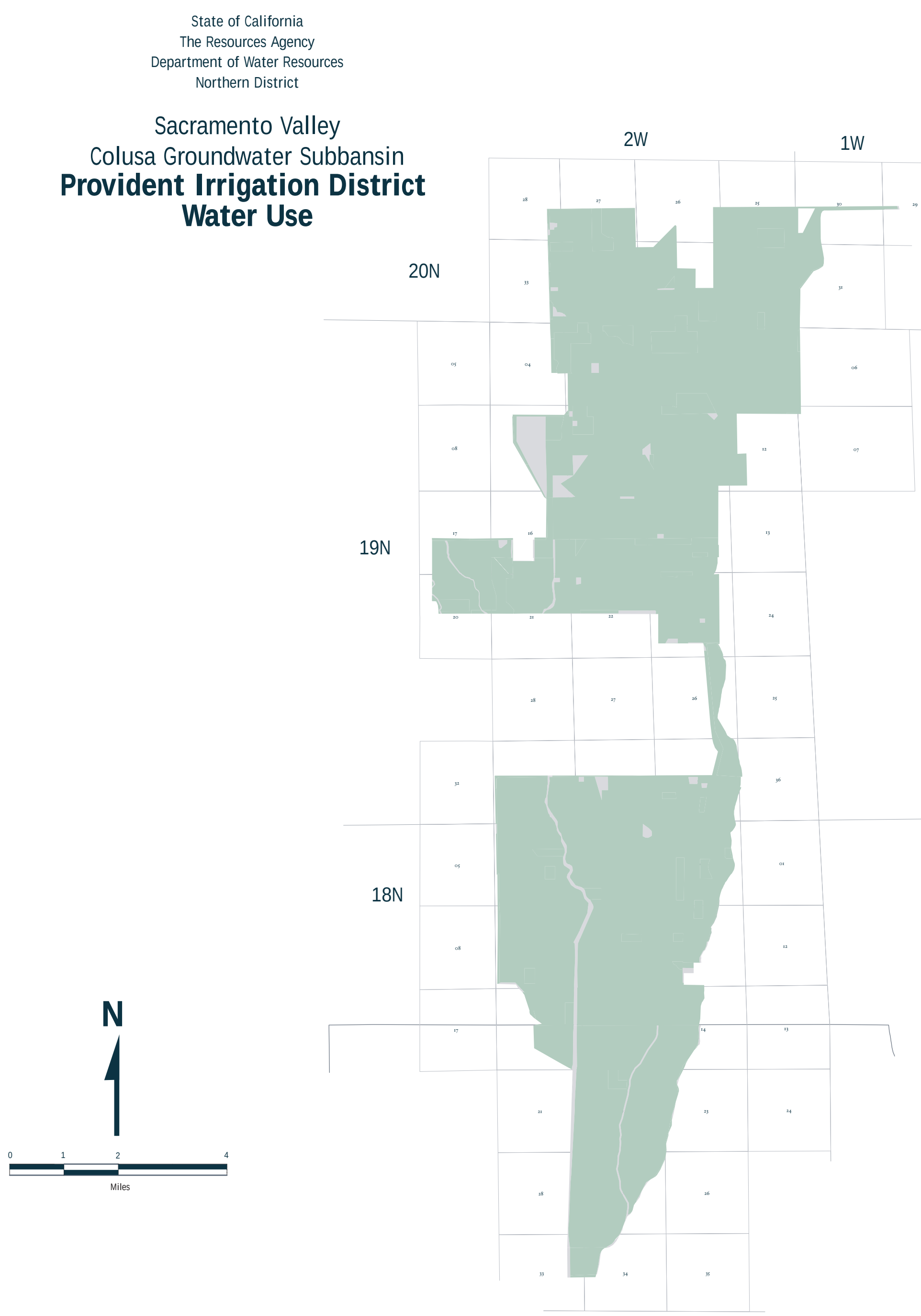
Groundwater Movement. In the northern portion of the district near Glenn, groundwater flows generally to the southeast toward the Sacramento River, at a gradient of about 4.8 feet per mile. Toward the southern end of the district, groundwater flow changes to a southerly direction at a gradient of about 2.5 feet per mile. The direction and gradient of groundwater flow are shown in Plates 3 and 4.

Groundwater Extraction. The PID service area covers about 15,800 acres over portions of Glenn and Colusa counties. DWR conducted land use surveys for Glenn and Colusa counties in 1993. The surveys show that the net irrigated acreage within PID was about 14,400 acres. Although PID owns several irrigation wells, the 1993 data show that nearly all of the 14,400 net acres were irrigated with surface water. Figure 16 shows general agricultural water use for the PID service area developed from historical land and water use data.

Water use areas delineated in Figure 16 show that about 15,300 acres within PID have the potential to be serviced by surface water. PID owns several production wells that are not associated with a particular property, but are capable of pumping into the distribution system. Because the groundwater source for these wells cannot be assigned to a particular property, Figure 16 shows the potential acreage irrigated by groundwater at zero. However, several hundred acres could likely be serviced by groundwater. Approximately 500 acres within the PID service area are non-irrigated.

Well Yield. In 1961, USGS compiled utility pump test records and summarized average well yield data for irrigation wells in the Orland-Willows and Colusa regions. PID is situated in the northeastern portion of the Colusa region and the southeastern portion of the

Figure 16
Water use map for PID



Potential Areas Irrigated with Surface Water (15,300 acres)
Potential Areas Irrigated with Groundwater (0 acres)
Potential Areas Irrigated with Surface Water and Groundwater (0 acres)
Potential Non-Irrigated Areas (500 acres)
Potential Areas Irrigated with Reclaimed Groundwater (0 acres)

Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

Orland-Willows region. The Colusa region extends from south of Willows to the Colusa-Yolo county line. The Orland-Willows region extends from the Tehama-Glenn county line to almost the Glenn-Colusa county line. The well yield estimates developed by USGS extend over a broad region, of which the PID service area covers only a small portion. Because USGS data are regional in scope and not specific to the PID service area, the well yield estimates for the PID area should be considered approximate. The well yield data from USGS investigation are summarized in Table 11.

Table 11
Well yield summary for PID

	Orland-Willows	Colusa
Number of Wells	238	59
Average Depth	210 ft	315 ft
Average Yield	1,030 gpm	1,690 gpm

There are 73 Well Completion Reports filed with DWR for the PID service area. Of the 73 reports, seven list well yield information. Six of these wells were classified as irrigation use, and one was domestic. Of the six irrigation wells, 50 percent had reported yields ranging from 3,000 to 3,500 gpm, and 50 percent had reported yields ranging from 5,000 to 6,050 gpm. The average yield from the six irrigation wells was about 4,350 gpm. The domestic well reported a yield of 160 gpm.

Well Depth. Well depth and well use data for the PID area were collected from Well Completion Reports filed with DWR. A summary of the minimum, maximum, and average well depth, listed by well use, is presented in Table 12.

About 32 percent of the wells in PID are drilled for domestic use, and 41 percent are drilled for irrigation. No municipal or industrial use wells are reported for the PID area. The average depth of the domestic wells within the PID area is about 106 feet, while the higher- producing irrigation wells tend to be deeper, with an average depth of 272 feet.

The well depth data were further analyzed using a cumulative frequency distribution and histogram of well depth for domestic and

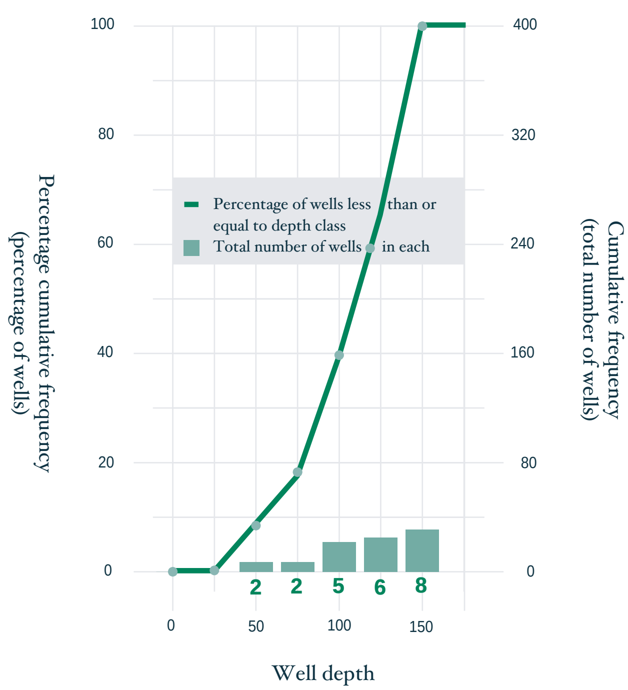
Table 12
Well depths in PID listed according to well use

Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	23	45	149	106
Industrial	0	-	-	-
Municipal	0	-	-	-
Irrigation	30	80	495	272
Other	20	12	102	33

irrigation wells. Figure 17 shows the cumulative frequency distribution and histogram of well depths for domestic well in the PID service area. A total of 23 domestic wells were analyzed in terms of cumulative frequency distribution with respect to well depth. The depth of domestic wells ranged from 45 to 149 feet.

The cumulative frequency curve and histogram in Figure 17 show that the number of wells in each 25-foot depth class increases with increasing depth. The number, or population, of domestic wells in

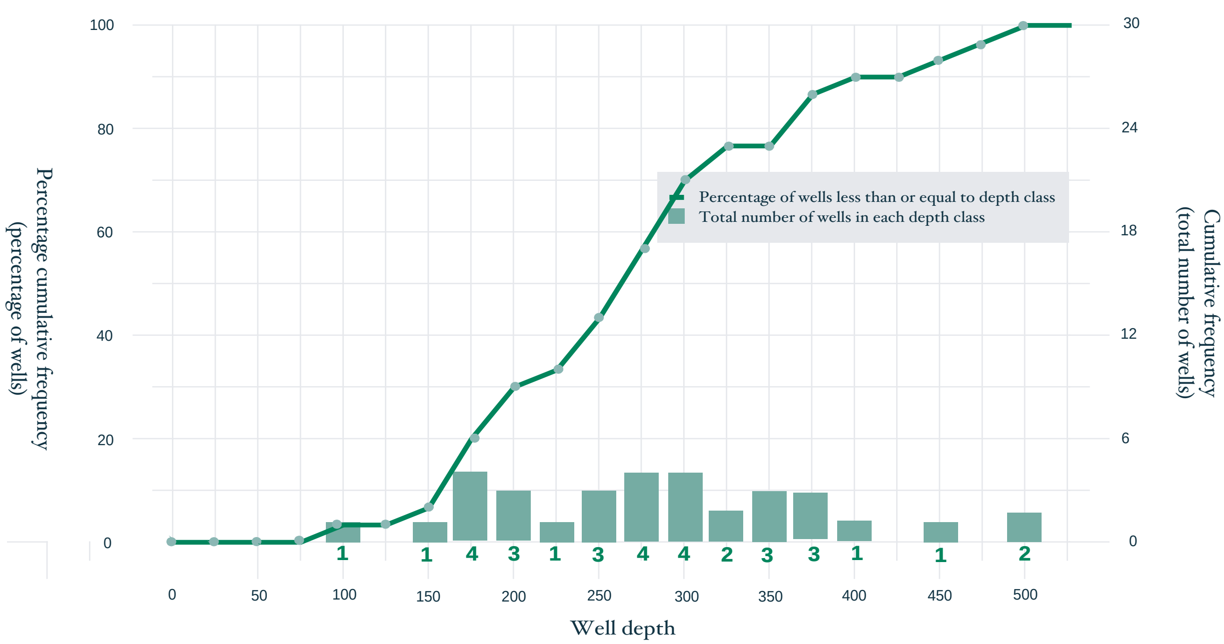
Figure 17
Cumulative frequency distribution and histogram of domestic well depth within PID



the PID area is too small to have a statistically meaningful distribution. The data in Figure 17 should be used only as a general reference of domestic well depth data.

Figure 18 illustrates the cumulative frequency distribution for the depth of irrigation wells in the PID service area. Thirty irrigation wells were used in the analysis. The irrigation wells ranged in depth from 80 to 495 feet

Figure 18
Cumulative frequency distribution and histogram of irrigation well depth within PID



The histogram in Figure 18 shows that the distribution of irrigation well depth data is asymmetrical, with no resemblance to a normal distribution curve. The asymmetrical distribution of the irrigation well depth data indicates that there is a range of irrigation well depths within PID and that there is no dominant well depth preference. The asymmetrical distribution could be the result of the small population of PID irrigation wells used in the statistical analysis.

The cumulative frequency curve of irrigation well depth data shows that:

> 50 percent of the irrigation wells are installed to a depth of about 260 feet or less,

10 percent of the irrigation wells are installed to a depth of about 160 feet or less.

Aquifer Transmissivity. DWR conducted aquifer performance tests in 1995 and 1996. The 1995 test consisted of extracting groundwater from State Well Number 20N/01W-30L01M, which is owned by PID, at a rate of 4,480 gpm for about 3.5 hours. Groundwater level measurements were recorded in the well, and also in nine observation wells. Well 20N/01W-30L01M draws water from the upper, unconfined portion of the aquifer system, and the lower, confined portion of the aquifer system. Analysis of the 1995 aquifer test data determined aquifer transmissivity to be 400,000 to 450,000 gallons per day per foot (gpd/ft) (DWR 1996).

The second aquifer test in 1996 consisted of pumping the same well for five days at an average rate of about 4,460 gpm. Groundwater level measurements were recorded in the pumping well and 11 observation wells during pumping and during the following five days of recovery. Analysis of the 1996 aquifer test data determined aquifer transmissivity to be about 386,000 gpd/ft (DWR 1996).

Specific Capacity. In 1961, USGS compiled utility pump test records and reported an average specific capacity of 85 and 76 gpm/ft for wells near the Colusa and Orland-Willows regions, respectively. PID is situated in the northeastern portion of the Colusa region and the southeastern portion of the Orland-Willows region. During the 1995 and 1996 aquifer tests, the specific capacity of PID State Well Number 20N/01W-30L01M was estimated to be 135 gpm/ft.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the PID area is about 20 feet. Estimates of groundwater storage capacity beneath PID assume a maximum aquifer saturation from a uniform depth of 20 feet to the base of fresh water at about 1,400 feet, and a service area of about 15,000 acres. The average specific yield for the upper 200 feet of aquifer in the PID area was determined by USGS in 1961 to range from 12 percent in the northern PID area to 7 percent in the southern PID area. For purposes of this investigation, the specific yield for the PID service area is estimated at 9 percent. Based on the above assumptions, the estimated groundwater storage capacity beneath PID is 1,860 taf. The methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

Groundwater in Storage. Table 13 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

Table 13
Estimated amount of groundwater in storage in PID

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	20 feet	1,860 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	245 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	260 feet	325 taf
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	160 feet	190 taf

Changes in Groundwater in Storage, 1989-99. The change in groundwater in storage for the PID service area was not estimated because of the lack of groundwater level monitoring data.

Conjunctive Management Potential. Investigations indicate that there is potential for conjunctive management within the PID service area. Findings from the 1996 study conducted by DWR indicate that during dry years, a PID conjunctive use project could yield between 30,000 and 45,000 af of additional water by substituting groundwater pumping for PID's Sacramento River surface water diversion.

Additional findings from the aquifer testing indicate that there is a strong interconnection between the Sacramento River and the shallow portion of the aquifer. Sustained pumping will reverse the regional groundwater flow gradient away from the Sacramento River and induce recharge from the Sacramento River. Recommendations from the 1996 study suggest that extraction wells designed for conjunctive use should draw from the aquifer at depths greater than 200 feet and be positioned at more than 1 mile from the Sacramento River.

Because of limited groundwater use in the district, the potential for increased in-lieu aquifer recharge appears limited. Moreover, the fine-grained nature of the soils makes direct recharge on a large scale impractical. Stored groundwater would best be recovered through groundwater substitution using existing irrigation wells, or through using new wells installed for groundwater recovery. Some of the infrastructure necessary to operate a conjunctive management project is in place.

Additional investigations are needed to determine the best approach to conjunctive use operations, including methods of groundwater recharge and recovery of stored groundwater. Studies are also needed to ensure compliance with the local groundwater management plans and ordinances.

Princeton-Codora-Glenn Irrigation District

Princeton-Codora-Glenn Irrigation District (PCGID) is west of the Sacramento River, in the north-central portion of the eastern Colusa Subbasin. The PCGID service area covers about 11,700 acres, extending south from Sidds Landing, past Princeton and the Glenn-Colusa county line. The western boundary of the PGCID is common to the eastern Provident Irrigation District boundary. Since 1918, PGCID has diverted Sacramento River water to members within its service area. Surface water within PCGID plays an important role in recharging the groundwater basin and in maintaining high, stable groundwater levels throughout the district. The PCGID service area is shown in Plate 1.

Groundwater Levels. DWR monitors groundwater levels in three wells within the PCGID service area. The PCGID groundwater level-monitoring grid consists of one active domestic, one idle-domestic, and one idle irrigation well. State Well Number 19N/02W-36H01M and State Well Number 19N/02W-36B01M are located in the central and southern parts of the district. State Well Number 19N/02W-13J01M is located near the northern end of the district, just outside the eastern portion of the PCGID service area. The period of record for these wells extends from the 1930s for State Well Number 19N/02W-13J01M, and the 1940s for the other two wells. Table 14 lists the PCGID monitoring wells, with the annual fluctuation of groundwater levels during normal and drought years.

Table 14
Annual fluctuation of groundwater levels within PCGID

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Annual GW Fluctuation: Drought Years (feet)
18N/02W-36B01M	Idle* Irrigation	Semi-confined	3 – 6	2 – 3
19N/02W-13J01M	Idle* Domestic	Unconfined	6 – 8	2 – 3
19N/02W-36H01M	Domestic	Unconfined	5 – 10	3 – 5

*Idle designation indicates a well that is currently non-operational

Historical groundwater level data for the PGCID monitoring wells indicate an unusual fluctuation of annual groundwater levels between unconfined and semi-confined portions of the aquifer system during normal and drought years. Typically, groundwater levels tend to fluctuate more during drought years than during normal years. However, the fluctuation of groundwater levels in the PCGID area averaged less in drought years than in normal years. The annual fluctuation of groundwater levels in the unconfined portion of the aquifer averages 5 to 10 feet during normal years, and 2 to 3 feet during drought years. The annual fluctuation of groundwater levels in the semi-confined portion of the aquifer system averages 3 to 6 feet during normal years and up to 2 to 3 feet during drought years.

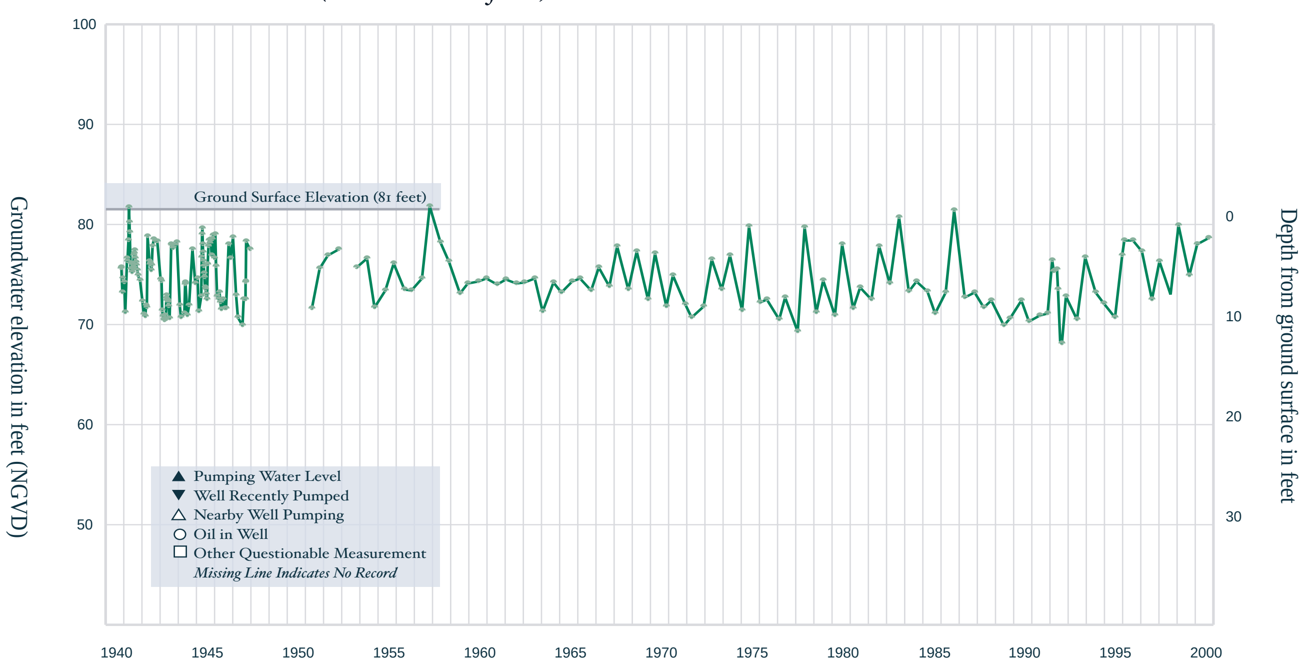
The reduced fluctuation in groundwater levels during drought years, compared with normal years, appears to result from a limited recovery in the spring groundwater levels. Summer groundwater levels for PCGID monitoring wells show little change between normal and drought years.

With only three monitoring wells in the PCGID service area, care should be taken in interpreting the meaningfulness of the groundwater level data. A more accurate estimate of aquifer response to drought conditions throughout the PCGID service area is limited because of the lack of monitoring well data.

Figure 19 is a hydrograph for State Well Number 19N/02W-36H01M, an active domestic well, and is representative of the unconfined aquifer conditions in the central portion of the district.

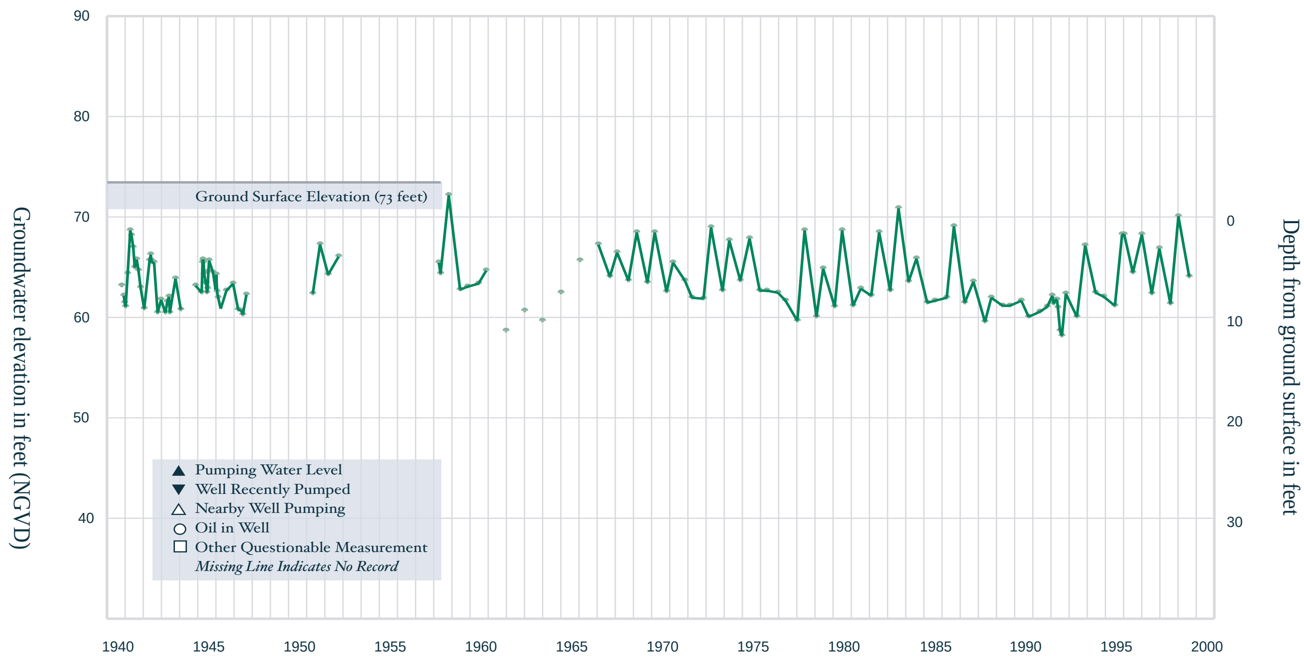
Figure 20 is a hydrograph for State Well Number 18N/02W-36B01M. This well is an idle irrigation well constructed in the upper-to-middle portion of the aquifer system. The hydrograph is representative of semi-confined groundwater levels in the southern portion of PCGID.

Figure 19
Hydrograph for State Well Number 19N/02W-36H01M
in the Colusa Subbasin and central PCGID
Well Use: *Domestic (Probable Unconfined)*



Comparing spring-to-spring groundwater levels in PCGID monitoring wells indicates that there has been little change in groundwater levels since the 1930s and 1940s. The monitoring wells show a decline in spring-to-spring groundwater levels associated with the 1976-77 and 1987-92 droughts, but little decline associated with summer water

Figure 20
Hydrograph for State Well Number 18N/02W-36B01M
in the Colusa Subbasin and southern PCGID
Well Use: *Domestic (Possible Semi-confined)*



levels. Historical groundwater level data from the three wells indicate that the basin fully recharges during years of normal and above-normal precipitation.

Groundwater Movement. Groundwater movement in the PCGID service area is similar to that of the PID. In the northern portion of the district, groundwater flow is generally to the south-southeast, toward the Sacramento River, at a gradient of about 5 feet per mile. Toward the southern end of the district, groundwater flow changes to a southerly direction at a gradient of 2.3 feet per mile. The direction and gradient of groundwater flow are shown in Plates 3 and 4.

Groundwater Extraction. The service area for PCGID covers about 11,700 acres in portions of Glenn and Colusa counties. DWR conducted land use surveys for these counties in 1993. These surveys show that the net irrigated acreage within PCGID was about 10,100 acres. Of the 10,100 net acres in production during 1993, approximately 1,200 acres were irrigated with groundwater, and about

8,900 acres were irrigated with surface water. The estimated amount of groundwater applied to the 1,200 acres was about 3,800 af. Figure 21 shows general agricultural water use for the PCGID service area developed from historical land and water use data.

Water use areas delineated in Figure 21 show that about 9,200 acres within PCGID have the potential to be serviced by surface water, 1,100 acres have the potential to be serviced by groundwater, and 200 acres have the potential to be serviced by a mixed water source. Approximately 300 acres within the PCGID service area are non-irrigated.

Well Yield. In 1961, USGS compiled utility pump test data and summarized average well yield data for irrigation wells in the Colusa region. PCGID is situated in the northeastern portion of the Colusa region. The Colusa region extends from south of Willows to the Colusa-Yolo county line. The well yield estimates developed by USGS extend over a broad region, of which the PCGID service area covers only a small portion. Because USGS data are regional, and not specific to the PCGID service area, the well yield estimates for the PCGID area should be considered approximate Well yield estimates from USGS are summarized in Table 15.

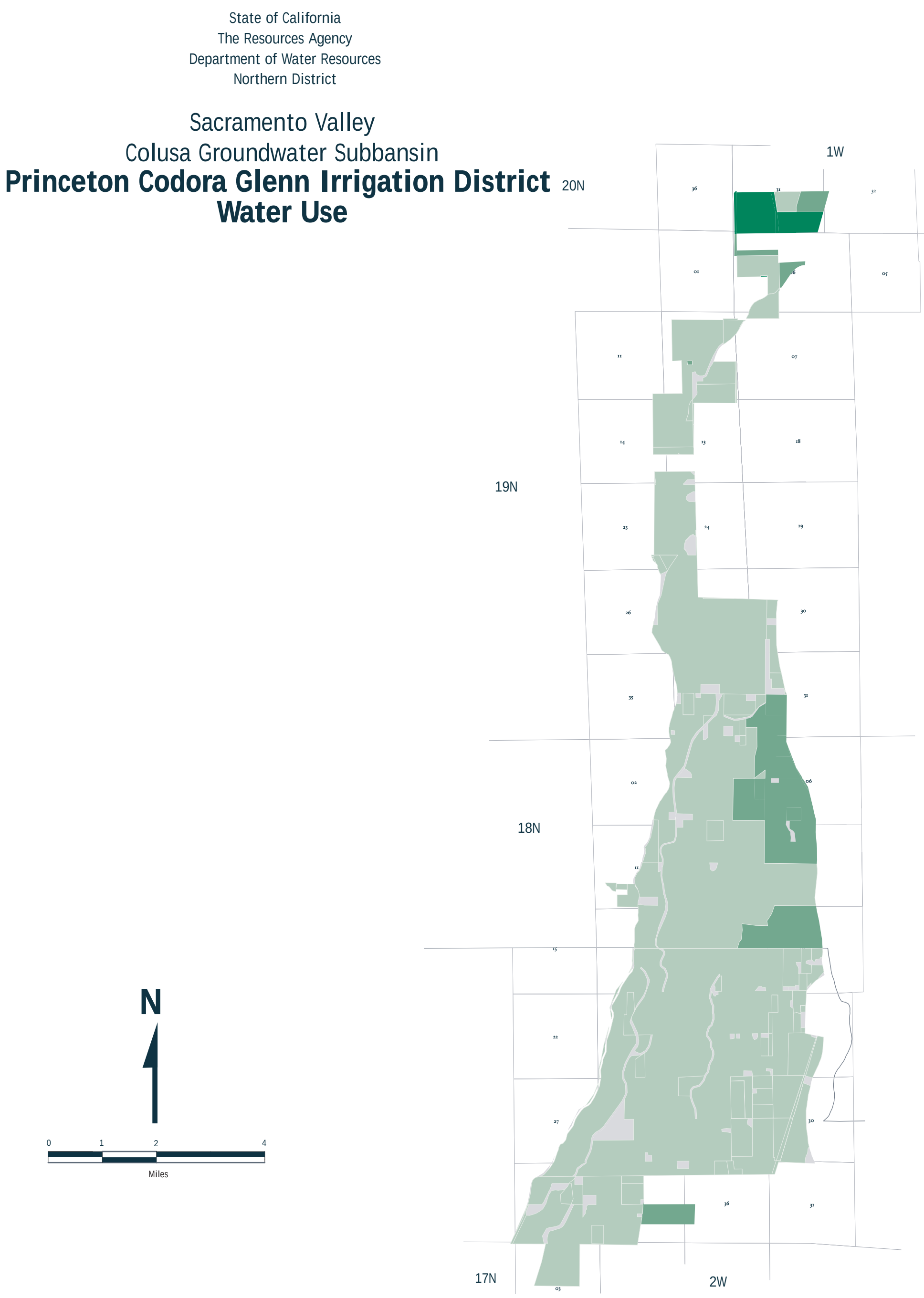
Table 15
Well yield summary for PCGID

	Colusa
Number of Wells	59
Average Depth	315 ft
Average Yield	1,690 gpm

There are 99 Well Completion Reports for PCGID service area are filed with DWR. Seven of these reports list well yield information. Three of these wells were reported as irrigation use and four were domestic. The irrigation Well Completion Reports indicated yields of 3,200, 3,300, and 3,500 gpm. The domestic wells reported yields of 50 to 100 gpm, with an average of 77 gpm.

Well Depth. Well depth and well use data for the PCGID area were collected from Well Completion Reports filed with DWR. A summary of the average well depth, listed by well use, is presented in Table 16.

Figure 21
Water use map for PCGID



- Potential Areas Irrigated with Surface Water (9,200 acres)
- Potential Areas Irrigated with Groundwater (1,100)
- Potential Areas Irrigated with Surface Water and Groundwater (200 acres)
- Potential Non-Irrigated Areas (300 acres)
- Potential Areas Irrigated with Reclaimed Groundwater (0 acres)

Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

Table 16
Well depths in PCGID listed according to well use

Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	52	36	224	108
Industrial	1	-	110	-
Municipal	2	155	393	274
Irrigation	26	108	438	224
Other	18	11	170	34

About 53 percent of the wells in PCGID are drilled for domestic use, and 26 percent are drilled for irrigation. Only one industrial and two municipal wells were reported for the area. The average depth of the domestic wells is about 108 feet, while the higher-producing irrigation and municipal wells tend to be deeper, with average depths of 224 and 274 feet, respectively.

The well depth data were further analyzed using the cumulative frequency distribution and histogram of well depth for domestic and irrigation wells. Figure 22 is a cumulative frequency distribution curve and histogram for the depth of domestic wells in the PCGID service area. A total of 52 domestic wells were used in the analysis. The domestic wells ranged in depth from 36 to 224 feet.

The histogram in Figure 22 shows the total number of wells associated with each 25-foot class interval. The distribution of domestic well data indicates that average well depth is less than the most frequently occurring well depth, or the depth class interval with the greatest number of wells.

The cumulative frequency curve of domestic well depth data for PCGID shows that:

50 percent of the domestic wells are installed to a depth of about 110 feet or less,

10 percent of the wells are installed to a depth of about 40 feet or less.

Figure 23 shows the cumulative frequency distribution and histogram for the depth of irrigation wells in the PCGID service area. A total of 26 irrigation wells were used in the analysis. The irrigation wells ranged in depth from 108 to 438 feet.

The asymmetrical distribution of the irrigation well depth data indicates that there is a range of irrigation well depths and that no dominant well depth preference exists. The asymmetrical distribution could also be the result of the small number of wells used in the statistical analysis.

The cumulative frequency distribution of irrigation well depth data shows that:

50 percent of the irrigation wells are installed to a depth of about 235 feet or less,

10 percent of the irrigation wells are installed to a depth of about 130 feet or less.

Specific Capacity. According to the 1961 USGS report, wells in the Colusa region are reported to have an average specific capacity of 85 gpm/ft. The specific capacity estimates developed by USGS extend over a broad region, of which the PCGID service area covers only a small portion. Because USGS data are regional and not specific to the PCGID service area, the specific capacity data derived from USGS investigation should be considered approximate.

As described in the Provident Irrigation District section, the specific capacity of State Well Number 20N/01W-30L01M was measured at 136 gpm/ft during the aquifer performance test. This well is located north of the PCGID.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the PCGID area is about 15 feet. Estimates of groundwater storage capacity beneath PCGID assume a maximum aquifer saturation from a uniform depth of 15 feet to the base of fresh water at 1,400 feet, a service area of about 11,700 acres, and a specific yield of 7.7 percent (Olmsted 1961). Based on these assumptions, the estimated groundwater storage capacity beneath PCGID is 1,250 taf. The methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

Figure 22
Cumulative frequency distribution and histogram of domestic well depth within PCGID

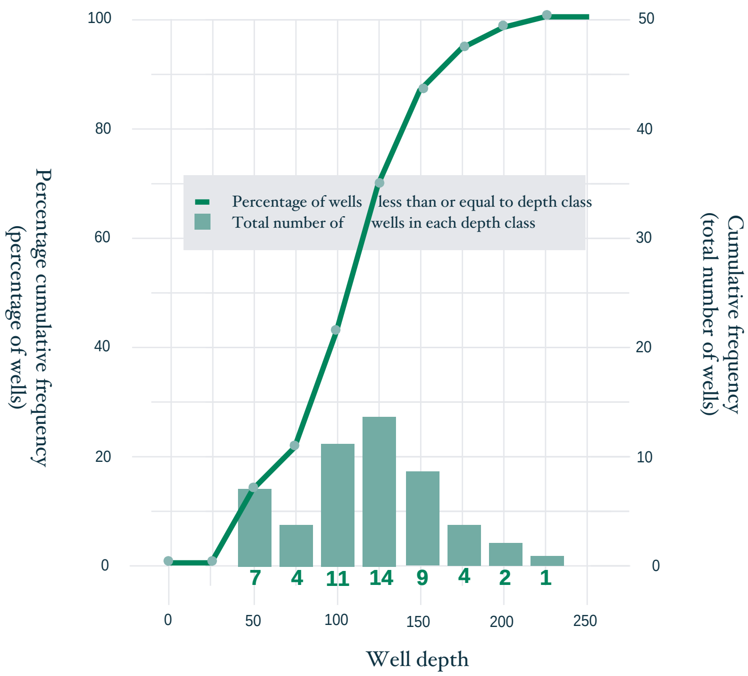
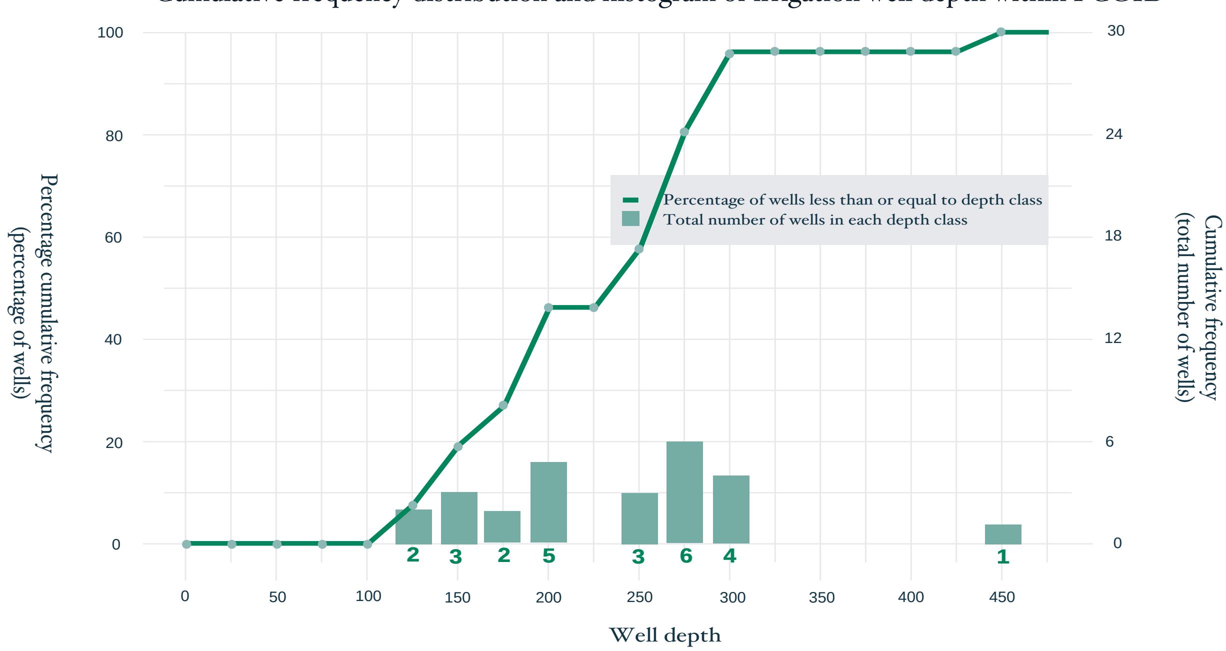


Figure 23
Cumulative frequency distribution and histogram of irrigation well depth within PCGID



Groundwater in Storage. Table 17 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

Changes in Groundwater in Storage. The estimated spring-to-spring change in groundwater in storage for the PCGID service area is shown in Figure 24. The two monitoring wells used to estimate the changes in groundwater in storage are listed in Figure 24, and their locations are shown in Plate 5. These wells are near the center and north end of the PCGID service area.

The spring-to-spring groundwater in storage has generally increased compared to the 1989 baseline storage level. During the drought of the early 1990s, groundwater storage dropped below the 1989 baseline storage level for one year, showing a decrease in storage of less than 1,000 af. Figure 24 also shows that the amount of groundwater in storage during spring 1999 is about 5,000 af greater than during spring 1989. The methodology used to estimate changes in groundwater in storage is discussed in Chapter 1.

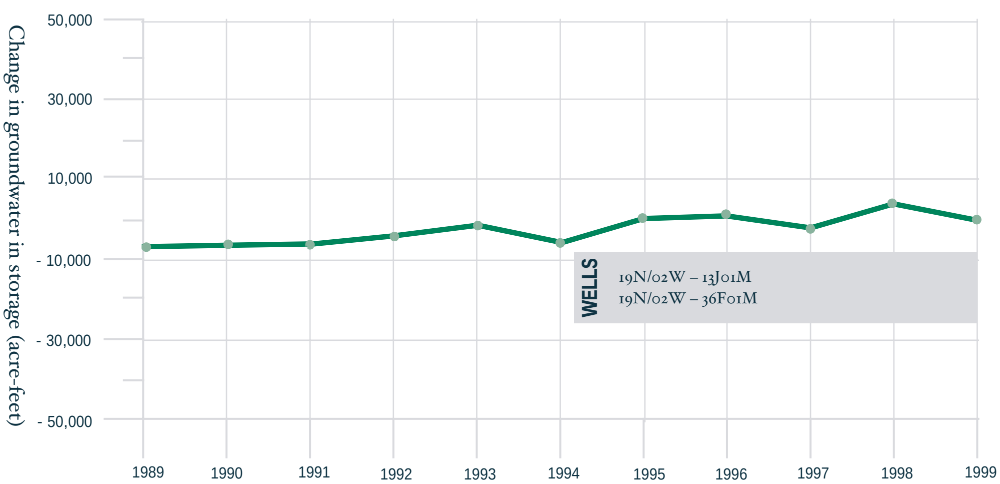
Conjunctive Management Potential. Data indicate that, with proper design, there is some potential for conjunctive management in the PCGID service area. Typically, in-lieu recharge would be the preferred method of aquifer recharge in this area. In-lieu recharge requires the delivery of surface water to areas irrigated by groundwater. The stored groundwater would best be recovered through groundwater substitution using existing wells or newly installed groundwater recovery wells.

Additional investigations are needed to determine the optimum approach to conjunctive use operations, including methods of groundwater recharge and recovery of stored groundwater. Additional studies are also needed to ensure compliance with the local groundwater management plans and ordinances.

Table 17
Estimated amount of groundwater in storage in PCGID

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	15 feet	11,700 TAF
A uniform lowering of groundwater levels to 200 feet	200 feet	165 TAF
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	230 feet	200 TAF
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	130 feet	105 TAF

Figure 24
Changes in groundwater in storage in PCGID, 1989-99



Maxwell Irrigation District

Maxwell Irrigation District (MID) is in the central portion of the Colusa Subbasin, about 10 miles west of the Sutter Buttes in Colusa County. Bordered by Glenn-Colusa Irrigation District to the north and west, MID covers about 8,300 acres. MID has a history of supplying Sacramento River surface water to users within its service area. Surface water use within MID plays an important role in recharging the groundwater basin and maintaining high, stable groundwater levels throughout the district. The MID service area is shown in Plate 1.

Groundwater Levels. Little information is available to characterize the groundwater levels in the district. DWR monitors groundwater levels in only one well within the district. The well is a domestic well of intermediate depth along the west side of the district. Table 18 lists the monitoring well along with the annual fluctuation of groundwater levels during normal and drought years. The monitoring well is shown in Plate 5.

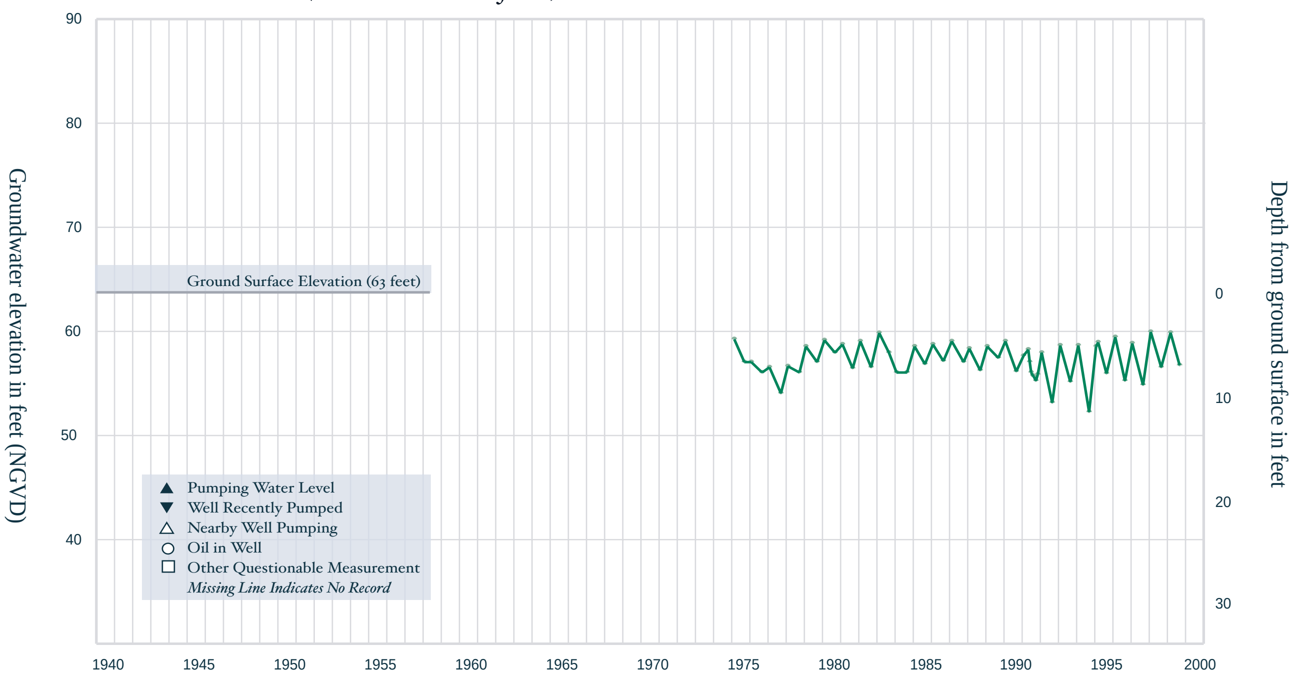
Groundwater level data from State Well Number 16N/03W-14H02M indicate that the annual fluctuation of groundwater levels in the unconfined to semi-confined portion of the aquifer system is between 2 and 4 feet during years of normal precipitation and 4 to 6 feet during periods of drought. No information is available about the confined portion of the aquifer.

Table 18
Annual fluctuation of groundwater levels within MID

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Drought Years (feet)
16N/03W-14H02M	Domestic	Semi-confined	2 - 4	4 – 6

Figure 25 is a hydrograph for State Well Number 16N/03W-14H02M. It shows a small to moderate change in seasonal groundwater levels in the western MID service area. Groundwater levels may be considered representative of local wells that draw water from the confined or semi-confined portions of the Tehama Formation.

Figure 25
Hydrograph for State Well Number 16N/03W-14H02M in the Colusa Subbasin and western MID
Well Use: *Domestic (Possible Semi-Confined)*

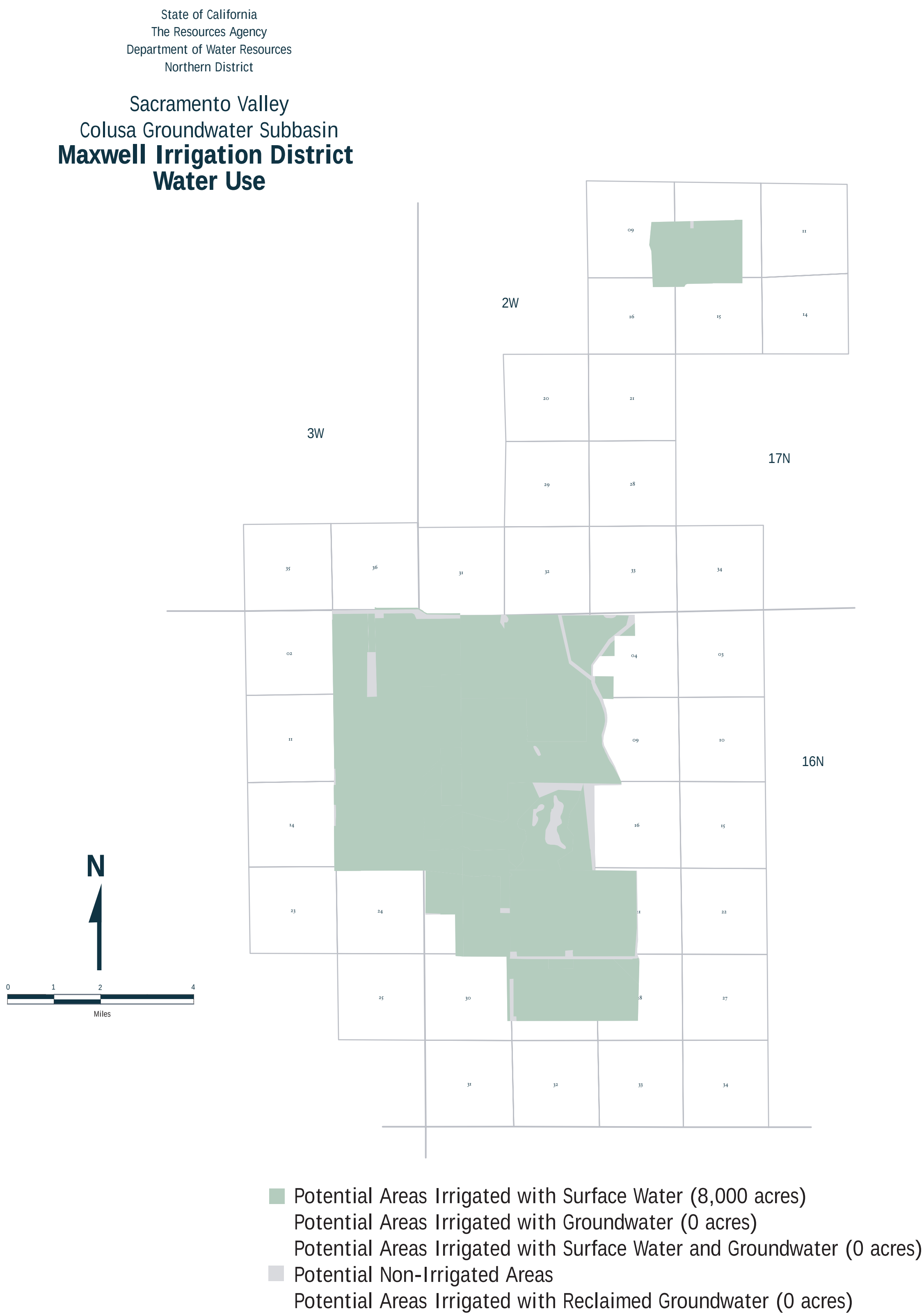


Groundwater Movement. Groundwater in MID moves southeasterly toward the Sacramento River at a gradient of about 4.8 feet per mile. Toward the southern end of the district, groundwater flow changes to a more southerly direction at a gradient of 2.5 feet per mile. The direction and gradient of groundwater flow are shown in Plates 3 and 4.

Groundwater Extraction. The MID service area covers about 8,300 acres within Colusa County. In 1993, DWR conducted land use surveys for the county. The surveys show that the net irrigated acreage within MID, which includes irrigated seasonal and permanent wetlands, was about 7,700 acres. The 1993 data indicate that all of the 7,700 net acres were irrigated with surface water. Figure 26 shows general agricultural water use for the MID service area developed from historical land and water use data.

Water use areas delineated in Figure 26 show that about 8,000 acres within MID have the potential to be serviced by surface water. Currently, no acreage has the potential to be serviced by groundwater or a mixed water source.

Figure 26
Water Use Map for MID



Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

Well Yields. In 1961, USGS compiled utility pump test records and summarized the average well yield data for irrigation wells in the Colusa region (Olmsted 1961). The MID service area is situated in the south-central portion of the region, which extends from just south of Willows to the Colusa-Yolo county line. The well yield estimates developed by USGS extend over a broad region, of which the MID service area covers only a small portion. Because USGS data are regional and not specific to the MID area, the well yield information should be considered approximate. Well yield estimates from USGS investigation are summarized in Table 19.

Table 19
Well yield summary for the MID

	Colusa
Number of Wells	59
Average Depth	315 ft
Average Yield	1,690 gpm

There are 36 Well Completion Reports filed at DWR for the MID service area. Of the 36 reports, five list well yield information. Two of the wells were reported as irrigation use, and three were domestic. The irrigation well reports listed yields of 2,000 and 3,500 gpm. The domestic well reports listed yields of 100, 300, and 300 gpm.

Well Depth. Well depth and well use data for the MID area were collected from Well Completion Reports filed with DWR. A summary of the minimum, maximum, and average well depth, listed by well use, is presented in Table 20.

About 40 percent of the wells in MID are drilled for domestic use, and 20 percent are drilled for irrigation. No municipal or industrial use wells are reported for the MID area. The average depth of the domestic wells within the MID area is about 247 feet. This is deeper than the average depth of domestic wells in some of the surrounding districts. The average depth of the irrigation wells is about 264 feet.

The number and distribution of well data for the MID area are too small for an adequate characterization of well depth using statistical methods.

Table 20
Well depths in MID listed according to well use

Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	13	75	570	247
Industrial	0	-	-	-
Municipal	0	-	-	-
Irrigation	6	137	335	264
Other	12	12	235	34

Specific Capacity. According to the 1961 USGS report, wells in the Colusa region have an average specific capacity of 85 gpm/ft. The specific capacity estimates developed by USGS extend over a broad region, of which the MID service area covers only a small portion. Because USGS data are regional and not specific to the MID service area, the specific capacity data should be considered approximate.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the MID area is about 15 feet. Estimates of groundwater storage capacity beneath the MID area assume a maximum aquifer saturation from a uniform depth of 15 feet to the base of fresh water at 1,400 feet, a service area of about 8,300 acres, and a specific yield of 7.7 percent (Olmsted 1983). Based on these assumptions, the estimated groundwater storage capacity beneath MID is 885 taf. The methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

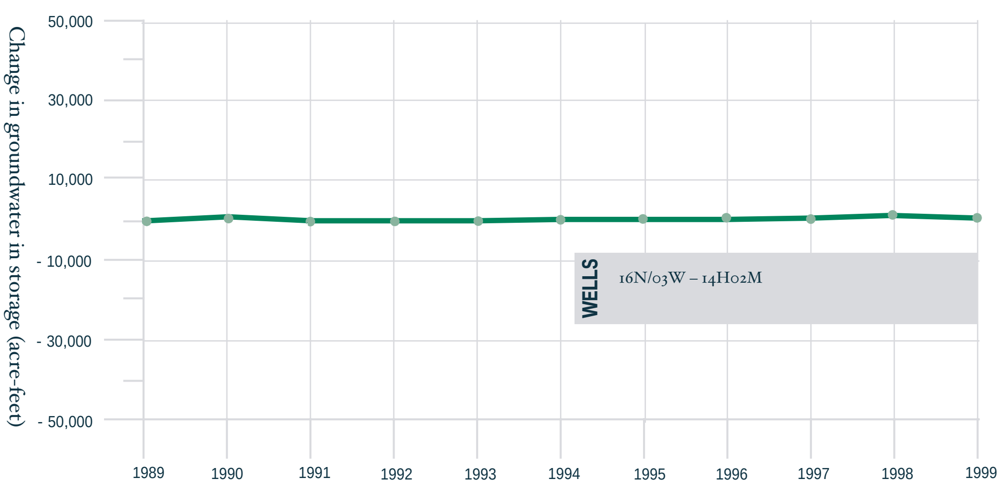
Groundwater in Storage. Table 21 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

Changes in Groundwater in Storage, 1989-99. The estimated spring-to-spring change in groundwater in storage for the MID service area is illustrated in Figure 27. The MID monitoring well used to estimate changes in groundwater in storage is listed in Figure 27, and its location is shown in Plate 5. This well is near the west side of the MID service area.

Table 21
Estimated amount of groundwater in storage in MID

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	15 feet	885 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	120 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	300 feet	180 taf
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	150 feet	85 taf

Figure 27
Changes in groundwater in storage in MID, 1989-99



There is little change in the spring-to-spring groundwater in storage compared to the 1989 baseline storage level. The amount of groundwater in storage decreased less than 500 af during the drought of the early 1990s, and increased less than 1,000 af in spring 1998 and 1999. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

Conjunctive Management Potential. Little groundwater data exist for the MID due to its small size and lack of monitoring wells. Additional investigations are needed to determine the best approach to conjunctive use operations, including methods of groundwater recharge and recovery of stored groundwater. Additional studies are also needed to ensure compliance with the local groundwater management plans and ordinances.

Based on aquifer production in the surrounding district areas, it is assumed that there is some potential for conjunctive management within the MID service area. Typically, in-lieu recharge would be the preferred method of aquifer recharge in this area. In-Lieu recharge requires the delivery of surface water to areas irrigated by groundwater. The stored groundwater would best be recovered through groundwater substitution using existing irrigation wells or newly installed recovery wells.

Reclamation District 108

Reclamation District 108 (RD 108) is at the southern end of the Colusa Subbasin, and covers an area of about 58,000 acres between the Colusa Basin Drain and the Sacramento River. The District's northern border extends between Grimes and Arbuckle in Colusa County. The southern border follows a southeastern trend from Dunnigan to south of the Sycamore Slough Pumping Plant in Yolo County.

RD 108 is irrigated almost solely with Sacramento River water. Historical use of surface water has helped maintain the local aquifer system at a full state. However, groundwater extraction from neighboring districts causes seasonal fluctuations in some parts of the aquifer system. The service area for RD 108 is shown in Plate 1.

Groundwater Levels. DWR monitors groundwater levels in one well within RD 108. The well, State Well Number 13N/01E-11A01M, is a domestic well of intermediate depth located along the northeast side of the district. Historically, four other wells have been monitored within RD 108 between 1942 and 1979. Monitoring these wells was discontinued in the mid- to late 1970s. Table 22 lists the RD 108 monitoring wells, along with the annual fluctuation of groundwater levels during normal and drought years. Monitoring wells are shown in Plate 5.

Table 22
Annual fluctuation of groundwater levels within RD 108

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Drought Years (feet)
12N/01E-10H01M	—	Unconfined	2 – 3	—
12N/01E-15Q01M	—	Semi-confined	6 – 12	—
12N/01E-25A01M	—	Unconfined	2 - 5	—
13N/01E-11A01M	Domestic	Unconfined	2 – 3	8 – 12
14N/01W-32R01M	Observation	Unconfined	2 – 5	—

Note: — indicates data was not available

The annual fluctuation of groundwater levels in the unconfined portion of the aquifer system averages 2 to 5 feet during normal precipitation years, and up to 12 feet during drought years. Annual fluctuation of groundwater levels in the semi-confined portion of the aquifer system averages 6 to 12 feet during normal years. No semi-confined or confined wells were monitored through recent drought periods.

Due to the lack of groundwater level data within RD 108, eight additional monitoring wells adjacent to the south, west, and north sides of the district were analyzed for changes in groundwater levels. Seven of the wells are within 1 mile of the service area boundary, and one is within 2 miles. The selected wells from the area surrounding RD 108 represent groundwater levels from unconfined, confined, and semi-confined portions of the aquifer system. Table 23 lists the monitoring wells surrounding RD 108, along with the annual fluctuation of groundwater levels during normal and drought years. Monitoring wells are shown in Plate 5.

Table 23
Annual fluctuation of groundwater levels from wells adjacent to RD 108

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Annual GW Fluctuation: Drought Years (feet)
11N/01E-03D01M	—	Confined	18 – 20	22 – 26
11N/01E-03D02M	—	Confined	21 – 23	26 – 28
11N/01E-03E01M	—	Confined	22 – 35	38 – 40
11N/01E-04E02M	—	Confined	21 – 28	30 – 40
12N/01W-01G01M	—	Unconfined	2 – 4	—
12N/01W-14M01M	—	Semi-confined	10 – 20	22 – 30
14N/01E-21L01M	Domestic	Unconfined	2 – 3	8 – 13
14N/01W-12A01M	Irrigation	Confined	8 – 12	15 – 19

*Idle designation indicates a well that is currently non-operational

The annual groundwater fluctuation for the unconfined portion of the aquifer is 2 to 4 feet during normal precipitation years and up to 13 feet during drought years. State Well Number 12N/01W-14M01M, constructed in the semi-confined portion of the aquifer system approximately 2 miles west of the district, shows groundwater level fluctuations ranging from 10 to 20 feet during normal years and up to 22 to 30 feet during drought years. Annual fluctuation of groundwater levels in the confined portion of the aquifer system is larger, ranging from 8 to 35 feet during normal years and up to 40 feet during drought years.

Figure 28 is the hydrograph for State Well Number 13N/01E-11A01M. This well is a domestic well of intermediate depth located in the northeast portion of RD 108, adjacent to the Sacramento River. This well monitors the upper aquifer system and is representative of the unconfined portion of the aquifer in the northeast portion of the area.

Figure 29 is a hydrograph for State Well Number 11N/01E-3E01M. This well is approximately 1 mile south of the district and is representative of groundwater levels in the confined portion of the aquifer system, near the southern end of the RD 108 service area.

Figure 28
Hydrograph for State Well Number 13N/01E-11A01M in the Colusa Subbasin and northeastern RD 108
Well Use: *Domestic (Probable Unconfined)*

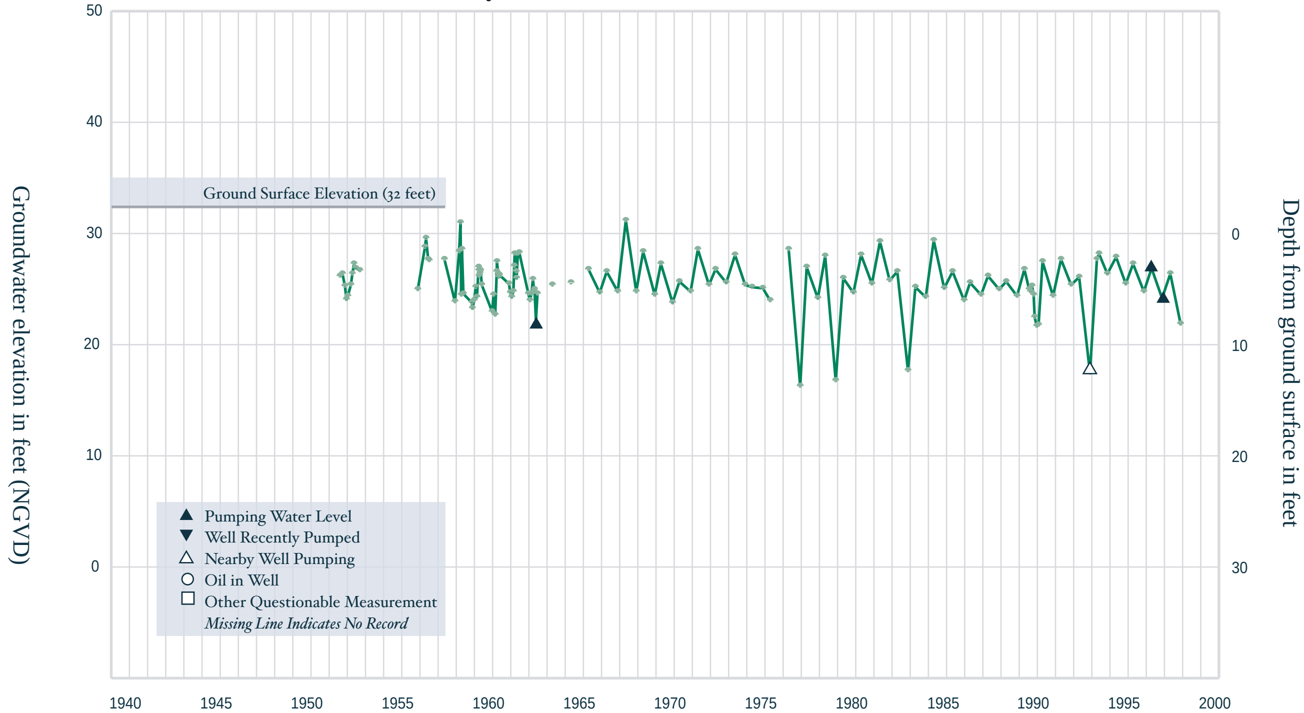
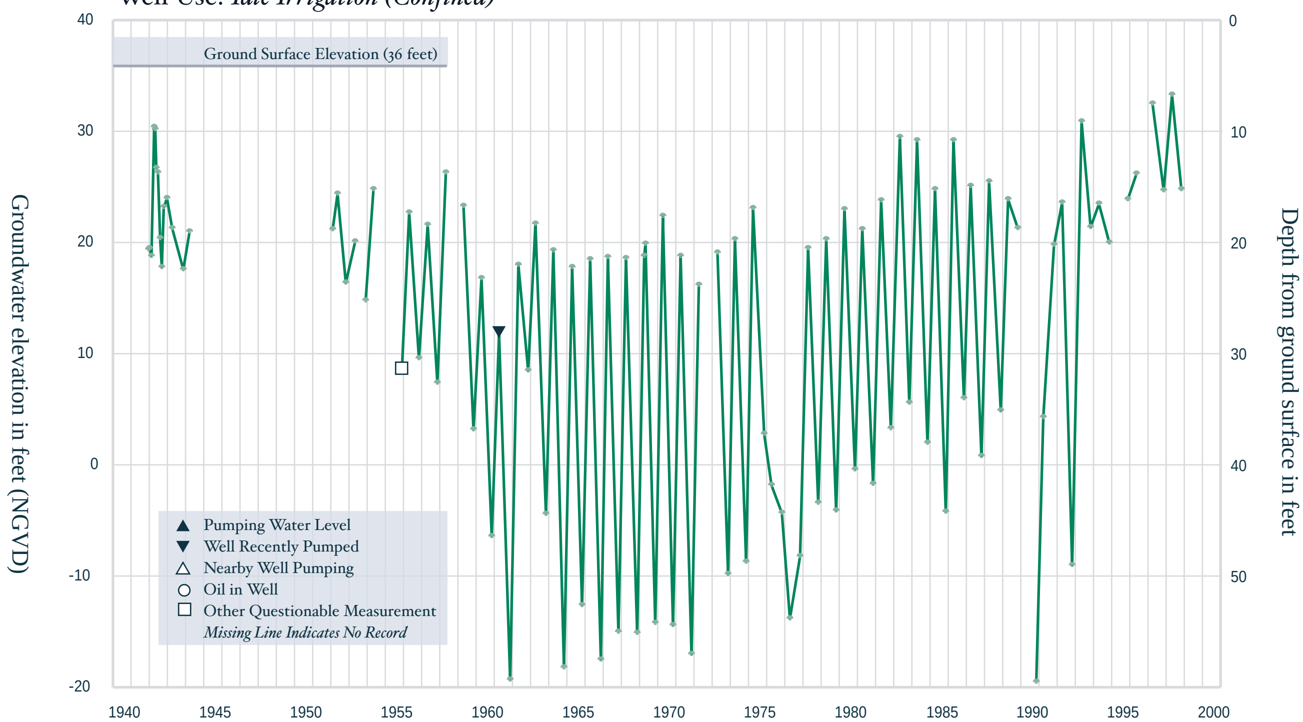


Figure 29
Hydrograph for State Well Number 11N/01E-03E01M in the Colusa Subbasin, south of RD 108
Well Use: *Idle Irrigation (Confined)*



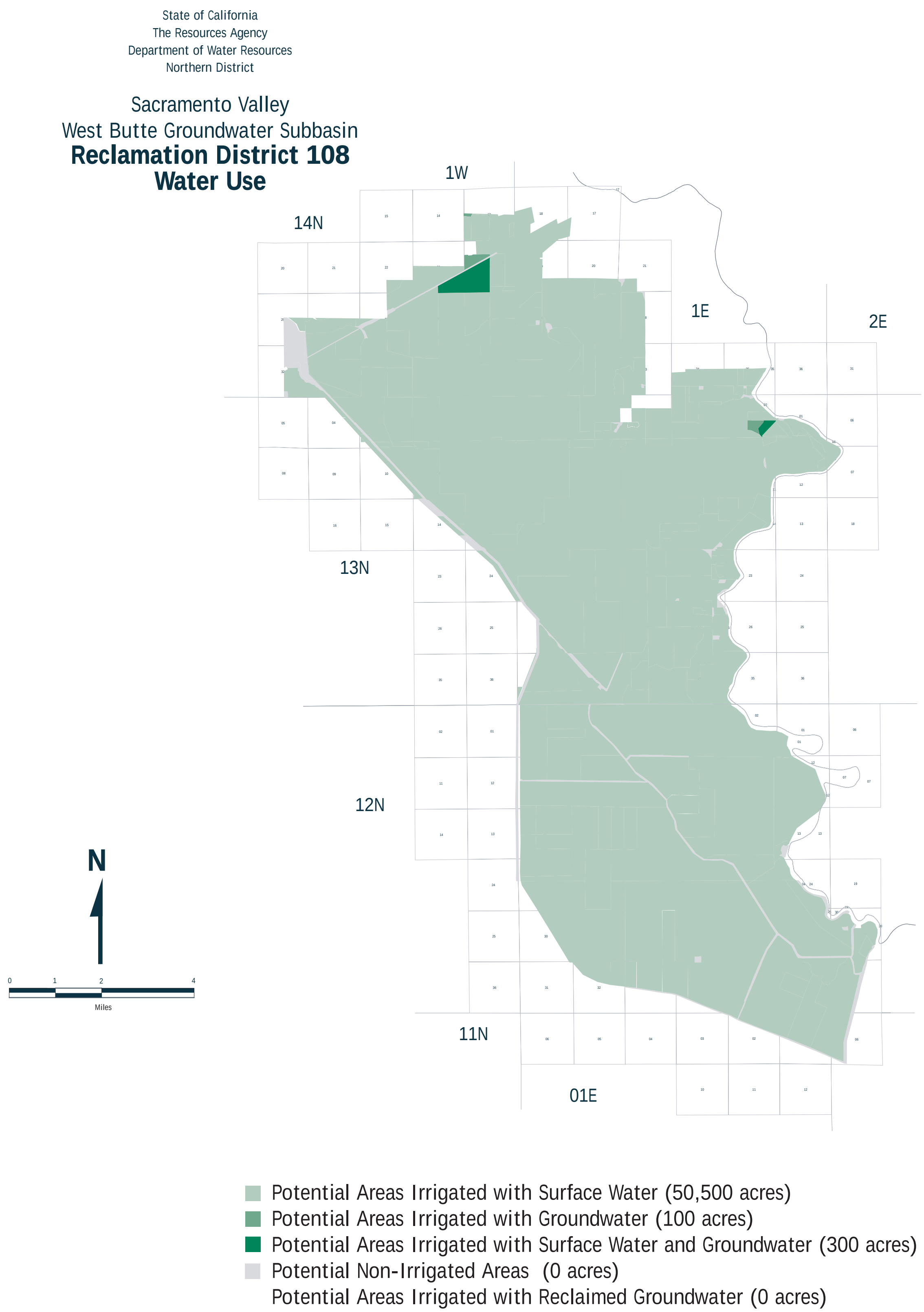
DWR recently installed 12 multi-completion wells in RD 108 as part of a conjunctive use feasibility investigation. These wells were installed to delineate the subsurface geology within the district and to independently monitor groundwater levels in each of three aquifer zones identified during the investigation. Too little data have been collected at this time to adequately characterize groundwater levels in each of the aquifer zones.

Groundwater Movement. The direction and gradient of groundwater movement is fairly uniform throughout RD 108. Groundwater generally flows to the southeast, toward the Sacramento River. The gradient of groundwater movement is slightly greater than 2 feet per mile in the northern portion of the district and slightly less than 2 feet per mile in the southern portion. The direction and gradient of groundwater movement are shown in Plates 3 and 4.

Groundwater Extraction. Reclamation District 108 covers about 58,000 acres within Yolo and Colusa counties. DWR conducted land use surveys for the counties in 1988 and 1993. The surveys show that the net irrigated acreage for RD 108 during these years was about 49,600 acres. Out of the 49,600 net acres in production, approximately 200 were irrigated with groundwater, and about 49,400 acres were irrigated with surface water. Because of the crop type and high soil moisture conditions associated with the 1988 and 1993 growing seasons, little groundwater was applied to the 200 acres during these years. The water distribution system within the district allows for maximum reuse of tail-water from up-gradient service areas. Some of the land and water use estimates for applied surface water could be higher than actual use because of extensive reuse within the district.

Historically, RD 108 has pumped groundwater as a supplemental supply during times of imposed surface water deficiencies, such as those that occurred during the 1991 Drought Water Bank. Figure 30 shows general agricultural water use for the RD 108 service area that was developed from historical land and water use data.

Figure 30
Water use map for RD 108



Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

Water use areas delineated in Figure 30 show that about 50,500 acres within the district have the potential to be serviced by surface water, about 100 acres have the potential to be serviced by groundwater, and 300 acres have the potential to be serviced by a mixed water source.

Well Yield. In 1961, USGS compiled utility pump test records and summarized average well yield data for irrigation wells in the Colusa and Verona-Knights Landing regions (Olmsted 1961). RD 108 is situated in the southern portion of the Colusa region and the north-eastern portion of the Verona-Knights Landing region. The Colusa region extends south of Willows to the Colusa-Yolo county line. The Verona-Knights Landing region covers a 5- to 10-mile strip along both sides of the Sacramento River from the Colusa-Yolo county line, south to Sacramento. The well yield estimates developed by USGS extend over large areas, of which the RD 108 service area covers only a small portion. Because USGS data are regional and not specific to the RD 108 service area, the well yield information should be considered an approximation of well yield conditions in the area.

Table 24
Well yield summary for the RD 108

	Verona-Knights Landing	Colusa
Number of Wells	45	59
Average Depth	303 ft	315 ft
Average Yield	740 gpm	1,690 gpm

There are 119 Well Completion Reports are filed with DWR for the RD 108 service area. Of the 119 reports, seven list well yield information. Three wells were reported as irrigation use, two were domestic, and two were of unknown use. Of the three irrigation wells, two had a reported yield of 5,000 gpm, and one had reported a yield of 4,000 gpm. The two domestic wells had reported yields of 525 and 800 gpm. The two unknown wells had reported yields of 2,750 and 3,500 gpm.

Well Depth. Well depth and well use data for the RD 108 area were collected from Well Completion Reports filed with DWR. A summary of the minimum, maximum, and average well depth, listed by well type, is presented in Table 25.

Table 25
Well depths in the RD 108 listed according to well use

Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	20	83	400	194
Industrial	2	260	316	288
Municipal	1	223	223	223
Irrigation	23	130	850	461
Other	73	8	760	104

About 17 percent of the wells were drilled for domestic use, and about 19 percent were drilled for irrigation. One municipal and two industrial use wells were also reported for the area. The average depth of the domestic wells within the district is about 194 feet. The average depth of the irrigation wells is about 460 feet.

The number and distribution of wells in the RD 108 service area are too small for an accurate characterization of well depth using statistical methods.

Specific Capacity. In 1961, USGS compiled utility pump test records and reported an average specific capacity of 85 and 42 gpm/ft for wells in the Colusa and Verona-Knights Landing regions (Olmsted 1961) . Because USGS data are regional and not specific to the RD 108 area, the specific capacity data derived from the USGS investigation should be considered an approximation.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the RD 108 area is about 10 feet. Estimates of groundwater storage capacity beneath the district assume a maximum aquifer saturation from a uniform depth of 10 feet to the base of fresh water at about 1,200 feet, and a service area of about 58,000 acres. The average specific yield was estimated by USGS to range between 5.5 and 9.6 percent for the upper 200 feet of the aquifer beneath RD 108. The average specific yield of the area is estimated at 7.5 percent. The estimated groundwater storage capacity beneath the RD 108 area is about 5,180 taf. The methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

Groundwater in Storage. Table 26 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

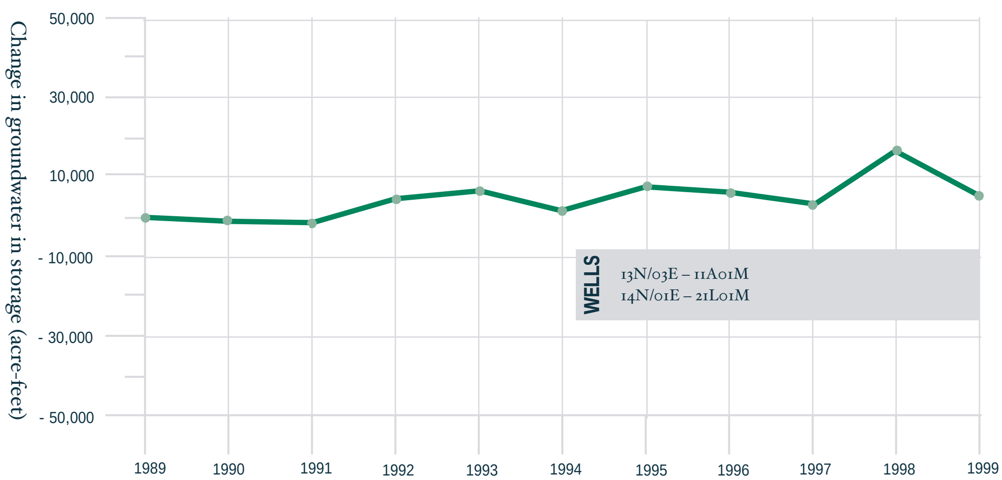
Table 26
Estimated amount of groundwater in storage in RD 108

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	10 feet	5,180 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	825 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	460 feet	1,960 taf
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	150 feet	610 taf

Changes in Groundwater in Storage, 1989-99. The estimated spring-to-spring change in groundwater in storage for the RD 108 service area is illustrated in Figure 31. The two monitoring wells used to estimate changes in groundwater in storage are listed in Figure 31. Their locations are shown in Plate 5.

The spring-to-spring groundwater in storage dropped below the 1989 baseline storage level during the drought of the early 1990s, then recovered through the mid to late 1990s. Figure 31 also shows that the amount of groundwater in storage during spring 1999 is about 5,000 af greater than during spring 1989. Methodology used to estimate changes in groundwater in storage is discussed in Chapter 1.

Figure 31
Changes in groundwater in storage in RD 108, 1989-99



Conjunctive Management Potential. Although there has been little groundwater use in the district, there is potential for future conjunctive management if new facilities are developed. DWR completed a pre-feasibility report on the conjunctive use potential of RD 108 in 1997. The report concluded that a cost-effective project could be developed that could produce about 35,000 af of dry-year water supply. Additional studies are needed to determine the best approach to conjunctive use operations, including methods of groundwater recharge and recovery of stored groundwater. Studies are also needed to ensure compliance with local groundwater management plans and ordinances.

Typically, in-lieu recharge would be the preferred method of aquifer recharge in this area. In-lieu recharge requires the delivery of surface water to areas irrigated by groundwater. The stored groundwater would best be recovered through groundwater substitution using existing wells or newly installed recovery wells.

Sacramento Valley Groundwater Basin, West Butte Subbasin

The West Butte Subbasin covers about 284 square miles in the north-central Sacramento Valley. The subbasin is bounded on the south and the west by the Sacramento River, on the northeast by the Chico Monocline, on the east by Butte Creek, and on the north by Big Chico Creek. Surface water use is widespread in the southern portion of the subbasin, and groundwater use is prevalent along the Sacramento River and the central to northern portions of the subbasin. The only SRSC service area within the West Butte Subbasin is Reclamation District 1004. The West Butte Subbasin and the SRSC service areas are shown in Plate 1.

The aquifer system of the basin is composed of late Tertiary to Quaternary age deposits. Tertiary deposits within the West Butte Subbasin consists of poorly sorted fluvial material of the Tehama Formation and volcanic deposits of the Tuscan Formation. The Tehama Formation consists of locally cemented silt, gravel, sand, and clay of fluvial origin deposited from the Coast Ranges. The Tuscan Formation consists of volcanic gravel and tuff breccia, coarse to fine-grained volcanic sandstone, conglomerate and tuff, tuffaceous silt, and clay derived mainly from andesitic and basaltic source rocks. Tertiary deposits occur at the surface along the eastern portion of the subbasin boundary and at approximately 100 feet below the surface near the Sacramento River. The maximum thickness of the Tertiary deposits is about 2,500 feet near the western edge of the West Butte Subbasin. Tertiary deposits are the primary source of groundwater for most irrigation and municipal wells in the subbasin. Wells in this zone range from about 150 to 600 feet deep and draw groundwater from multiple layers of moderate to high permeability.

Overlying the Tuscan Formation are alluvium, floodplain, and terrace deposits of Quaternary age. Thickness of the quaternary deposits is variable, ranging from several feet to over 100 feet. Quaternary deposits can provide moderate to large quantities of water to shallow irrigation and domestic wells in the subbasin.

The base of fresh water ranges from about 1,400 feet below ground surface in the northern subbasin to less than 500 feet in the southern subbasin, near the Sutter Buttes.

Reclamation District 1004

Reclamation District 1004 (RD 1004) is between the Sacramento River and Butte Creek in the southeastern portion of the West Butte Subbasin. The service area for RD 1004 covers about 24,500 acres, extending into Glenn, Colusa and Sutter counties. Most of the district is in Colusa County. Agricultural use of groundwater within RD 1004 is limited. Most agricultural water is supplied from the Sacramento River. The district has a history of supplying surface water to members within its service area. Application of surface water and limited groundwater extraction has helped maintain the aquifer beneath the area at a full state through most years. Because of the district's limited use of groundwater, data characterizing the local aquifer are largely unavailable. The RD 1004 service area is shown in Plate 1.

Groundwater Levels. DWR monitors groundwater levels in only one well in RD 1004. The well, State Well Number 18N/01W-35K01M, is a shallow domestic well in the north-central part of the district. Groundwater levels have been monitored semi-annually since the mid-1950s.

Because of the lack of groundwater level data within RD 1004, seven additional monitoring wells to the north, south, east, and west sides of the district were analyzed for changes in groundwater levels. Five of the wells are within 1 mile of the RD 1004 service area boundary, and two are within 2 miles. The selected wells from the surrounding area are domestic, irrigation, and observation wells representing groundwater levels from the unconfined, confined, and semi-confined portions of the aquifer system. The period of record for the surrounding wells dates to the 1930s for State Well Number 16N/01W-20F01M, the 1950s for State Well Number 18N/01W-17G01M, the 1960s for State Well Number 18N/01W-17G01M, the 1970s for State Well Number 18N/01W-32L01M, and the 1990s for the three observation wells. Table 27 lists the annual fluctuation of groundwater levels during normal and drought years for all eight monitoring wells. The monitoring wells are shown in Plate 5.

The annual fluctuation of groundwater levels in the unconfined to semi-confined portion of the aquifer system is from 2 to 12 feet

Table 27
Annual fluctuation of groundwater levels within RD 1004 and surrounding areas

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Drought Years (feet)
16N/01W-20F01M	Domestic	Unconfined	6 – 12	3 – 18
17N/01E-17F01M	Observation	Semi-confined	4 – 6	6 – 8
17N/01E-17F02M	Observation	Confined	5 – 7	6 – 10
17N/01E-17F03M	Observation	Confined	5 – 7	6 – 12
18N/01W-17G01M	Irrigation	Unconfined	5 – 10	12 – 18
18N/01W-22L01M	Irrigation	Composite	2 – 6	7 – 14
18N/01W-32L02M	Irrigation	Unconfined	6 – 8	2 – 15
18N/01W-35K01M	Domestic	Unconfined	2 – 3	1 – 2

during years of normal precipitation and 1 to 18 feet during years of drought. The annual groundwater fluctuation in the confined portion of the aquifer system, along the east side of the district, is from 5 to 7 feet during years of normal precipitation and 6 to 12 feet during years of drought. The annual fluctuation of groundwater levels was less during some drought years compared with years of normal precipitation because groundwater levels did not fully recover in the spring.

Figure 32 is a hydrograph for State Well Number 18N/01W-35K01M, a shallow domestic well in the north-central portion of the district. This hydrograph represents groundwater conditions in the unconfined portion of the aquifer system in the northern district area.

Figure 33 is a hydrograph for State Well Number 16N/01W-20F01M, a shallow domestic well just outside the district's southwestern boundary. This hydrograph represents groundwater levels in the unconfined portion of the aquifer system in the southern part of the district.

Comparing Figures 32 and 33 indicates that groundwater levels associated with the unconfined aquifer system show a greater annual fluctuation in the southern portion of the district than in the northern portion of the district.

Figure 32
Hydrograph for State Well Number 18N/01W-35K01M in the West Butte Subbasin and northern RD 1004
Well Use: *Domestic (Probable Unconfined)*

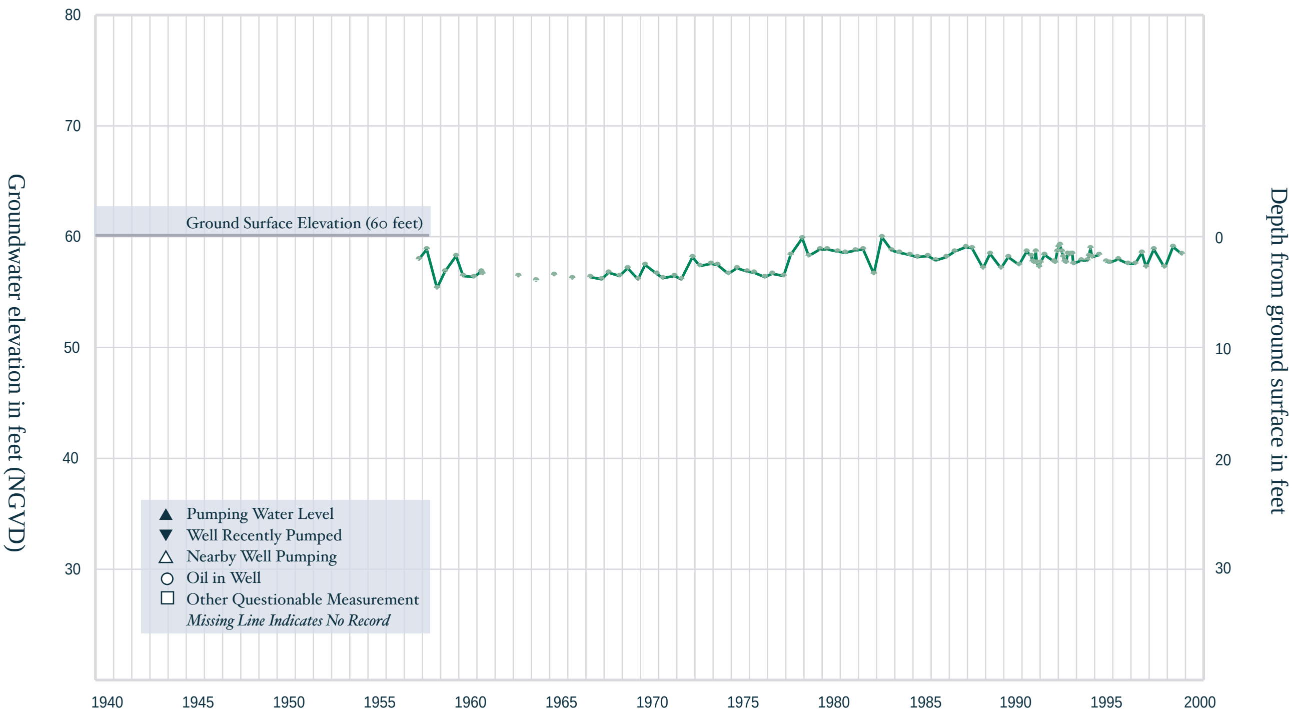
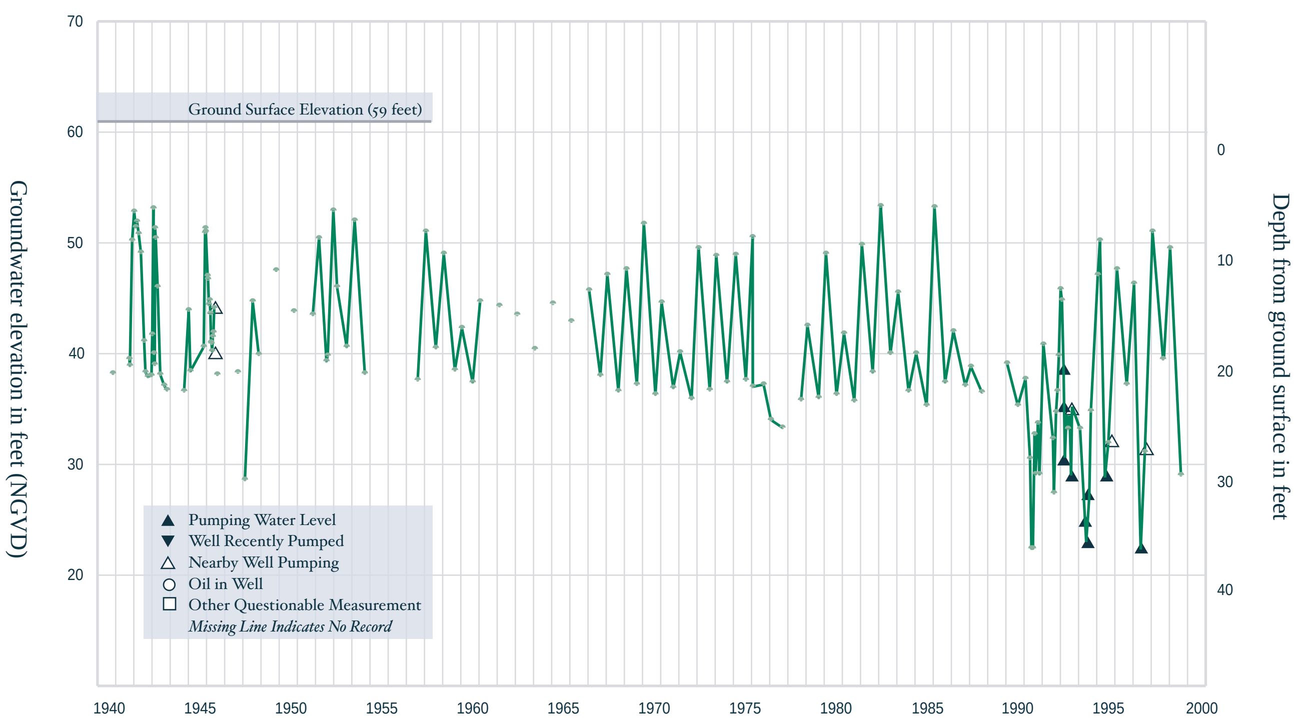


Figure 33
Hydrograph for State Well Number 16N/01W-20F01M in the West Butte Subbasin and southwestern RD 1004
Well Use: *Domestic (Definite Unconfined)*



Comparing spring-to-spring groundwater levels indicates that there has been little change in groundwater levels since the 1950s and 1960s. Monitoring wells within and around RD 1004 show a small decline associated with the 1976-77 and 1987-92 droughts, followed by full recovery. Groundwater level data indicate that the basin fully recharges during years of normal and above-normal precipitation.

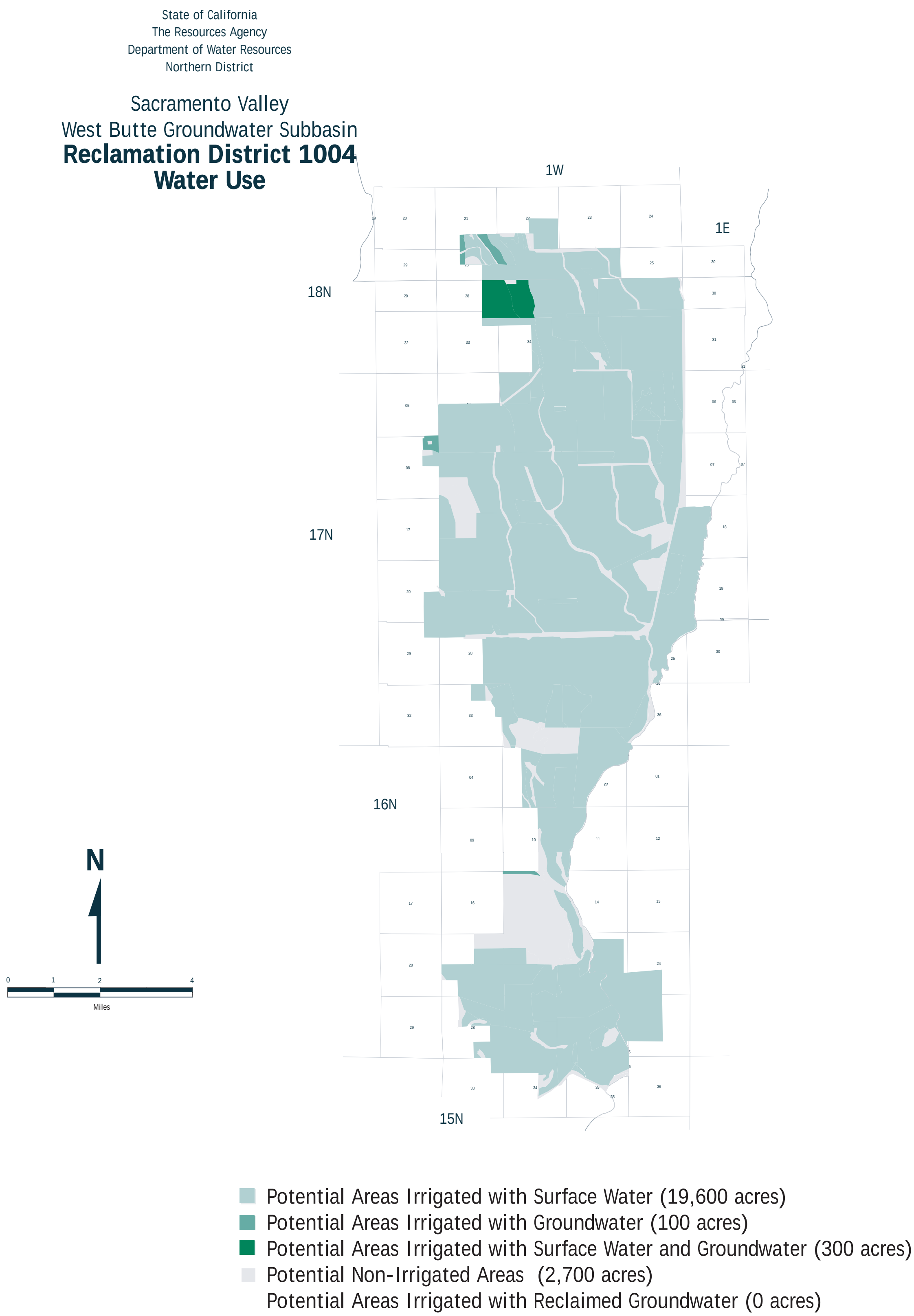
Groundwater Movement. In the northern part of the district, groundwater flows generally to the south-southeast. In the southern end of the district, groundwater flow changes to a more southerly direction. Overall, the groundwater gradient for RD 1004 is about 2.3 feet per mile. The direction and gradient of groundwater flow are shown in Plates 3 and 4.

Groundwater Extraction. RD 1004 covers about 24,500 acres over parts of Glenn, Colusa, and Sutter counties. DWR conducted land use surveys for Glenn and Colusa counties in 1993 and for Sutter County in 1990. The surveys show that the net irrigated acreage for RD 1004, which includes irrigated seasonal and permanent wetlands, was about 18,400 acres. Of the 18,400 net acres in production, approximately 18,200 were irrigated with surface water, and about 200 acres were irrigated with groundwater. The estimated amount of groundwater applied to the 200 acres was about 500 af. Figure 34 shows general agricultural water use for the RD 1004 service area developed from historical land and water use data.

Historically, Reclamation District 1004 has pumped groundwater to serve as a supplemental supply during times of imposed surface water deficiencies, such as those that occurred during the 1991 Drought Water Bank.

About 19,600 acres within the district have the potential to be serviced by surface water, 100 acres have the potential to be serviced by groundwater, and about 300 acres have the potential to be serviced by a mixed water source.

Figure 34
Water use map for RD 1004



Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

Well Yield. In 1961, USGS compiled utility pump test data and summarized average well yield data for irrigation wells in the Colusa region (Olmsted 1961). RD 1004 is situated in the east-central portion of the Colusa region, which extends from south of Willows to the Colusa-Yolo county line and east to Butte Creek. The well yield estimates developed by USGS extend over a broad region, and should be considered an estimate of well yield conditions in the RD 1004 service area. Well yield data from USGS investigation are summarized in Table 28.

Table 28
Well yield summary for RD 1004

	Colusa
Number of Wells	59
Average Depth	315 ft
Average Yield	1,690 gpm

There are 88 Well Completion Reports filed with DWR for the RD 1004 service area. Of the 88 reports, nine irrigation wells reported well yield information. Eight of the nine wells had a diameter of 12 inches or larger, and a reported yield of between 3,000 and 4,000 gpm. The remaining irrigation well had a diameter of 8 inches and a reported yield of 200 gpm.

Well Depth. About 14 percent of the wells in RD 1004 are for domestic use, and 59 percent are for irrigation. Only one industrial well was reported for the RD 1004 area. No municipal wells were reported. The average depth of the domestic wells within the district is about 174 feet, while the higher-producing irrigation wells

Table 29
Well depths in RD 1004 listed according to well use

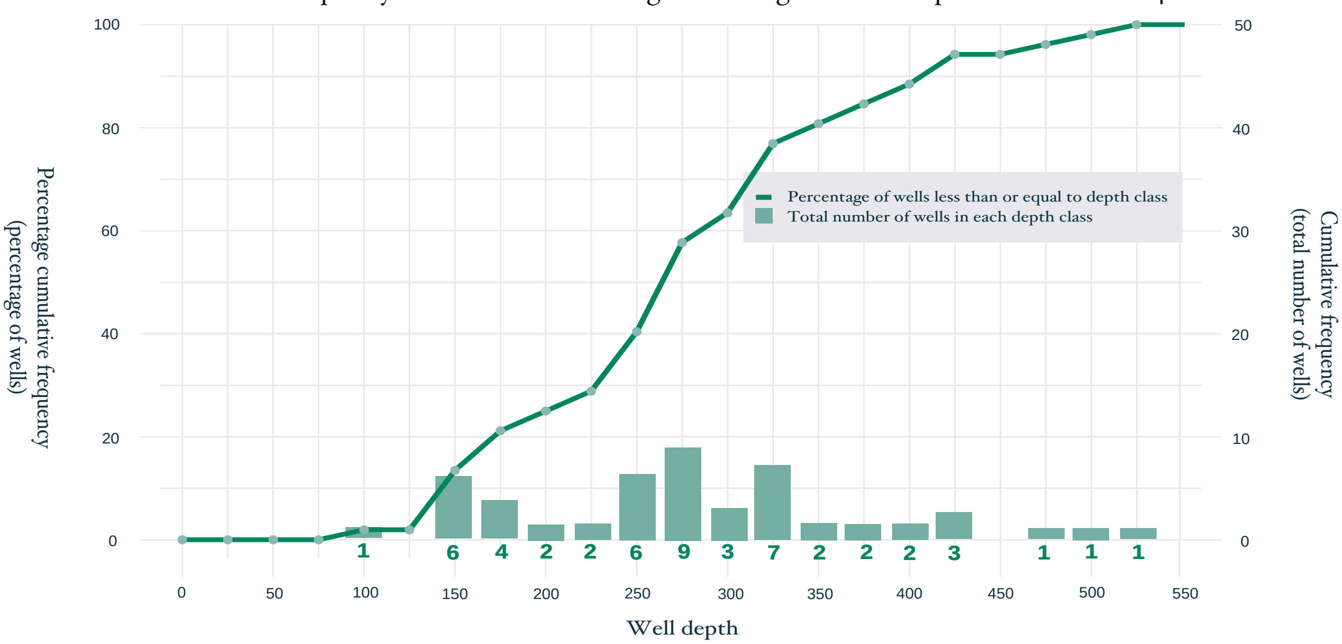
Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	12	46	491	174
Industrial	1	105	105	105
Municipal	0	-	-	
Irrigation	52	97	502	274
Other	23	12	710	84

tend to be deeper, with average depth of 274 feet.

The well depth data were further analyzed using the cumulative frequency distribution and histogram of well depth for RD 1004 irrigation wells shown in Figure 35.

Figure 35 shows the cumulative frequency distribution and histogram for the depth of irrigation wells in the RD 1004 service area. A total of 52 irrigation wells were used in the analysis. The irrigation wells ranged in depth from 97 to 525 feet.

Figure 35
Cumulative frequency distribution and histogram of irrigation well depth within RD 1004



Other than the cluster of six wells in the 125- to 150-foot depth range, the distribution of the irrigation well depth data is fairly normal, but spread over a range of well depths.

The cumulative frequency of irrigation well depth data for RD 1004 shows that:

50 percent of the irrigation wells are installed to a depth of about 260 feet or less,

10 percent of the irrigation wells are installed to a depth of about 140 feet or less.

Specific Capacity. According to the 1961 USGS investigation, wells located in the Colusa region have an average specific capacity of 85 gpm/ft. The Colusa region extends from south of Willows to the Colusa-Yolo county line and east to Butte Creek. Specific capacity estimates developed by USGS extend over a broad region, and should be considered an estimate of well yield conditions.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the RD 1004 area is about 10 feet. Estimates of groundwater storage capacity beneath the area assume a maximum aquifer saturation from a uniform depth of 10 feet to the base of fresh water at about 800 feet, and a service area of about 24,500 acres. The average specific yield was estimated by USGS to range between 8.6 and 14.3 percent for the upper 200 feet of the aquifer. For the purpose of this investigation, the average specific yield of the RD 1004 area is estimated at 12 percent. The estimated groundwater storage capacity beneath RD 1004 is 2,320 taf. The methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

Groundwater in Storage. Table 30 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

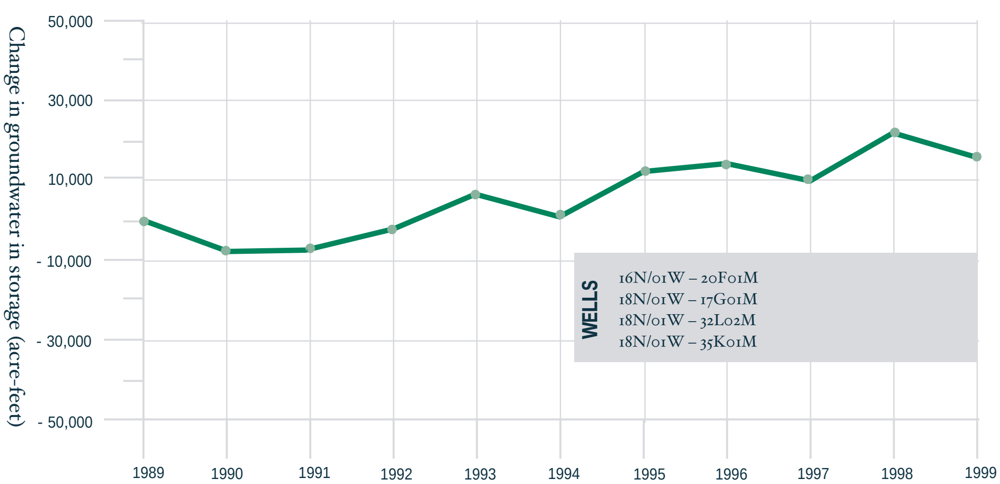
Changes in Groundwater in Storage, 1989-99. The estimated spring-to-spring change in groundwater in storage for the RD 1004 service area is shown in Figure 36. The four monitoring wells used to estimate the changes in groundwater in storage are listed in Figure 36, and their locations are shown in Plate 5. These wells are distributed fairly evenly within and around the district.

Figure 36 shows that the spring-to-spring groundwater in storage dropped below the 1989 baseline storage level during the drought of the early 1990s, and then recovered through the mid- to late 1990s. Figure 36 also shows that the amount of groundwater in storage during spring 1999 is about 15,000 af greater than during spring 1989. The methodology used to estimate changes in groundwater in storage is discussed in Chapter 1.

Table 30
Estimated amount of groundwater in storage in RD 1004

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	10 feet	2,320 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	560 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	260 feet	735 taf
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	140 feet	380 taf

Figure 36
Changes in groundwater in storage in RD 1004, 1989-99



Conjunctive Management Potential. Based on work in progress by DWR, it appears that some potential exists for improving RD 1004's dry-year water supply reliability through conjunctive management of their surface supplies and groundwater resources. Additional studies are needed to determine the best approach to conjunctive use operations, including methods of groundwater recharge and recovery of stored groundwater. Additional studies are also needed to ensure compliance with the local groundwater management plans and ordinances.

Typically, in-lieu recharge would be the preferred method of aquifer recharge in this area. In-lieu recharge requires the delivery of surface water to areas irrigated by groundwater. The stored groundwater would best be recovered through groundwater substitution using existing wells or newly installed recovery wells.

Sacramento Valley Groundwater Basin, West Sutter Subbasin

The West Sutter Subbasin covers about 170 square miles in the south-central portion of the Sacramento Valley. West Sutter Subbasin is bounded on the west and south by the Sacramento River, on the north by the Sutter Buttes, and on the east by the Sutter Bypass drain. Surface water is the predominant source of agricultural water in the subbasin. Sacramento River Settlement Contractors within the West Sutter subbasin include:

1. Sutter Mutual Water Company
2. Pelger Mutual Water Company

The West Sutter Subbasin and the Sacramento River Settlement Contractor service areas are shown in Plate 1.

Geologically, the West Sutter Subbasin is fairly complex. In 1971, Curtin characterized the hydrogeology of the subbasin and identified the cause of a saline mound of groundwater in the southeast portion of the subbasin. Geologic units in the subbasin include continental and clastic volcanic deposits of Tertiary to Quaternary age.

Quaternary age deposits include alluvial, steam channel and floodplain deposits of Pleistocene to Recent age. The Tertiary deposits include the Tehama, Laguna, Sutter, and Mehrten formations. The principal water-bearing formation in the West Sutter Subbasin is believed to be the Tehama Formation.

The Tehama Formation extends eastward from the western margin of the Sacramento Valley Groundwater Basin, dipping beneath the valley floor and forming the base of the continental deposits. The formation consists of alluvial material derived from the Coast Ranges. In the West Sutter Subbasin area, the Tehama Formation has a maximum thickness of about 2,000 feet. Along the eastern and northeastern margins of the Sacramento Valley, the Laguna and Mehrten formations dip westward toward the valley axis, where they likely interfinger with the Tehama Formation at depth beneath the West-Sutter Subbasin. In his 1971 thesis, Curtin identified a 150-foot-thick Upper Miocene basalt flow at the base of the Tehama Formation in the middle of the West Sutter Subbasin.

The Mehrten Formation is a sequence of late Miocene to middle Pliocene age reworked volcanic rocks consisting of "black sands," stream gravel, silt, and clay deposits interbedded with intervals of dense tuff breccia. The sand and gravel intervals are highly permeable and yield large quantities of water to agricultural wells. The tuff breccia intervals act as confining layers.

The Pliocene age Laguna Formation generally overlies the Mehrten Formation in the southeast portion of the Sacramento Valley. The Laguna Formation consists of interbedded alluvial gravel, sand, and silt. Permeability ranges from low to moderate.

Alluvium of the Sutter Buttes is exposed in the vicinity of where it has been uplifted by tectonic activity associated with the formation of the Buttes. The formation consists of thin-bedded to volcanic sediments transported by rivers from the Sierra Nevada. The Sutter Formation is roughly correlative with the Mehrten Formation.

Floodplain deposits occur between the Sutter Bypass and the Sacramento River, and overlie the Tehama Formation. Floodplain deposits consist primarily of silts and clays; however, along the western margin of the subbasin, they may be locally interbedded with stream channel deposits of the Sacramento River. Floodplain deposits are up to 150 feet thick (Curtin 1971). The floodplain deposits have low permeability and generally yield low quantities of water to wells. Wells completed in these deposits often produce brackish water.

Stream channel deposits include sediments deposited in the channels of active streams as well as overbank deposits of those streams. They consist primarily of unconsolidated silt, fine to medium grained sand, and gravel. Thickness of the deposits ranges from 0 to 130 feet. Sand and gravel zones in the younger alluvium are highly permeable and yield significant quantities of water to wells.

The alluvial fans form a ring around the Sutter Buttes and consist of volcanic and sedimentary detritus eroded from the Buttes and deposited around their perimeter. The deposits are poorly sorted and generally contain less than 10 percent coarse material. The maximum thickness of the alluvial fan deposits is 80 feet.

In the southeastern portion of the West Sutter Subbasin, the northwest-southeast trending Sutter Basin Fault exhibits a south-side-up displacement of about 550 feet (Curtin 1971). The Sutter Basin Fault extends across the Sutter Mutual Water Company at Township 13N, Range 2E and 3E, and continues through the Sutter Bypass to its terminus north of Nicolaus. Movement of saline connate water along the Sutter Basin Fault is believed to be caused by a large mound of saline water that exists in the east-central portion of the subbasin. The mound of connate water has displaced the fresh water in 2,000 feet of overlying post-Eocene sediments. The Upper Cretaceous age marine deposits are the primary source of the rising connate water. The fault cuts the Upper Cretaceous marine sands and allows saline water to rise along the fault into the post-Eocene alluvium (Curtin 1971).

Throughout the Sutter Basin, the base of fresh water is at a depth of less than 500 feet and rises to the surface in the southern part of the basin (Curtin 1971).

Sutter Mutual Water Company

The Sutter Mutual Water Company (SMWC) services about 51,100 acres in the southern portion of the West Sutter Subbasin in Sutter County. The SMWC service area is bordered by the Tisdale Weir on the north, the Sutter Bypass on the east, and the Sacramento River on the west. The SMWC has a history of supplying surface water to members in its service area. Surface water application, with limited groundwater extraction, has helped to maintain a full aquifer beneath SMWC. Because of SMWC's limited use of groundwater, data characterizing aquifer productivity and hydrogeology are largely unavailable. The SMWC service area is shown in Plate 1.

Groundwater Levels. DWR monitors groundwater levels in only one well in the SMWC. State Well Number 12N/02E-23K01M is a domestic well of intermediate depth located in the south-central portion of the district. Groundwater levels in the well have been monitored semi-annually since the early 1960s.

Historically, three other wells within the SMWC service area have been monitored for groundwater levels. State Well Number 13N/02E-34M01M was discontinued in 1964. State Well Number 11N/03E-08N01M and State Well Number 12N/02E-09D03M were discontinued in the early 1980s.

Because of the lack of groundwater level data within SMWC, two additional monitoring wells located outside the service area were used to analyze changes in groundwater levels. The well numbers for the two wells are State Well Number 14N/02E-26R01M and State Well Number 12N/03E-26R01M. State Well Number 14N/02E-26R01M is a domestic well located about 2 miles northeast of the district. This well has a discontinuous period of record dating from 1942 to 1977. State Well Number 12N/03E-26R01M is an irrigation well of intermediate depth located about 2 miles east of the southeastern service area boundary. Groundwater levels in State Well Number 12N/03E-26R01M have been monitored semi-annually from 1972 to the present. Table 31 lists the annual fluctuation of groundwater levels during normal and drought years for all six monitoring wells. The locations of the monitoring wells are shown in Plate 5.

Table 31
Annual fluctuation of groundwater levels for wells within and adjacent to Sutter Mutual Water Company

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Annual GW Fluctuation: Drought Years (feet)
11N/03E-08N01M	Domestic	Unconfined	3 – 5	6 - 8
12N/03E-26R01M	Irrigation	Confined	4 – 6	22 - 26
12N/02E-23K01M	Domestic	Unconfined	2 – 3	5
12N/02E-09D03M	Observation	—	2 – 4	—
13N/02E-34M01M	Ind./stock	Unconfined	4 – 6	5 - 8
14N/02E-26R01M	Domestic	Unconfined	2 – 4	—

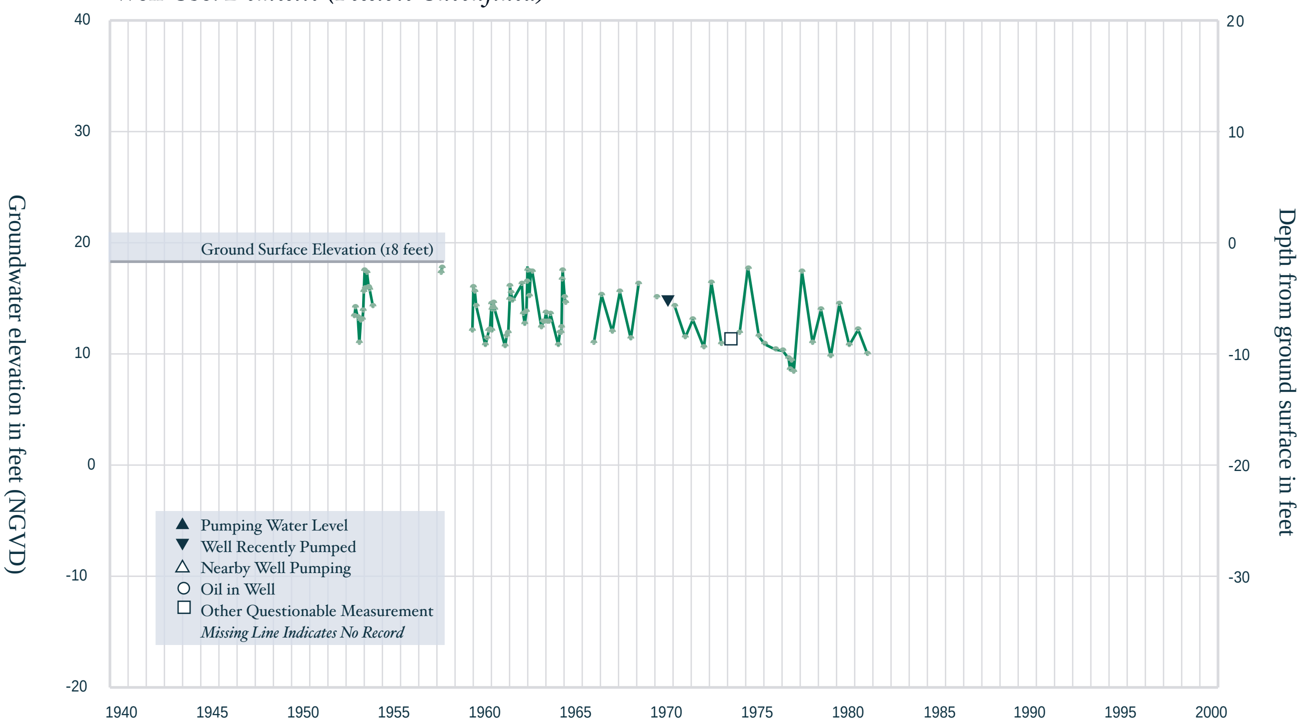
Note: — indicates data was not available

The annual groundwater fluctuation for the unconfined portion of the aquifer is 2 to 6 feet during normal precipitation periods and up to 8 feet during drought periods. State Well Number 12N/03E-26R01M, constructed in the confined portion of the aquifer system, shows groundwater level fluctuations ranging from 4 to 6 feet during normal years and up to 26 feet during drought years.

Figure 37 is the hydrograph for State Well Number 11N/03E-08N01M, a domestic well of intermediate depth located in the southern portion of the district. This well monitors the upper part of the aquifer system and is representative of the unconfined portion of the aquifer in the area.

Groundwater Movement. The movement of groundwater in the Sacramento Valley is from the east and west margins of the valley toward the Sacramento River and the north-south axial trough of the valley. SMWC is east of the Sacramento River along the north-south valley axis. In the northern portion of the SMWC, groundwater flow comes from the northwest and northeast at a gradient of about 2.3 feet per mile and converges in the center of the SMWC service area. Toward the southern portion of the district, groundwater gradients become flat, allowing the direction of movement to vary locally. The direction and gradient of groundwater flow is shown in Plates 3 and 4.

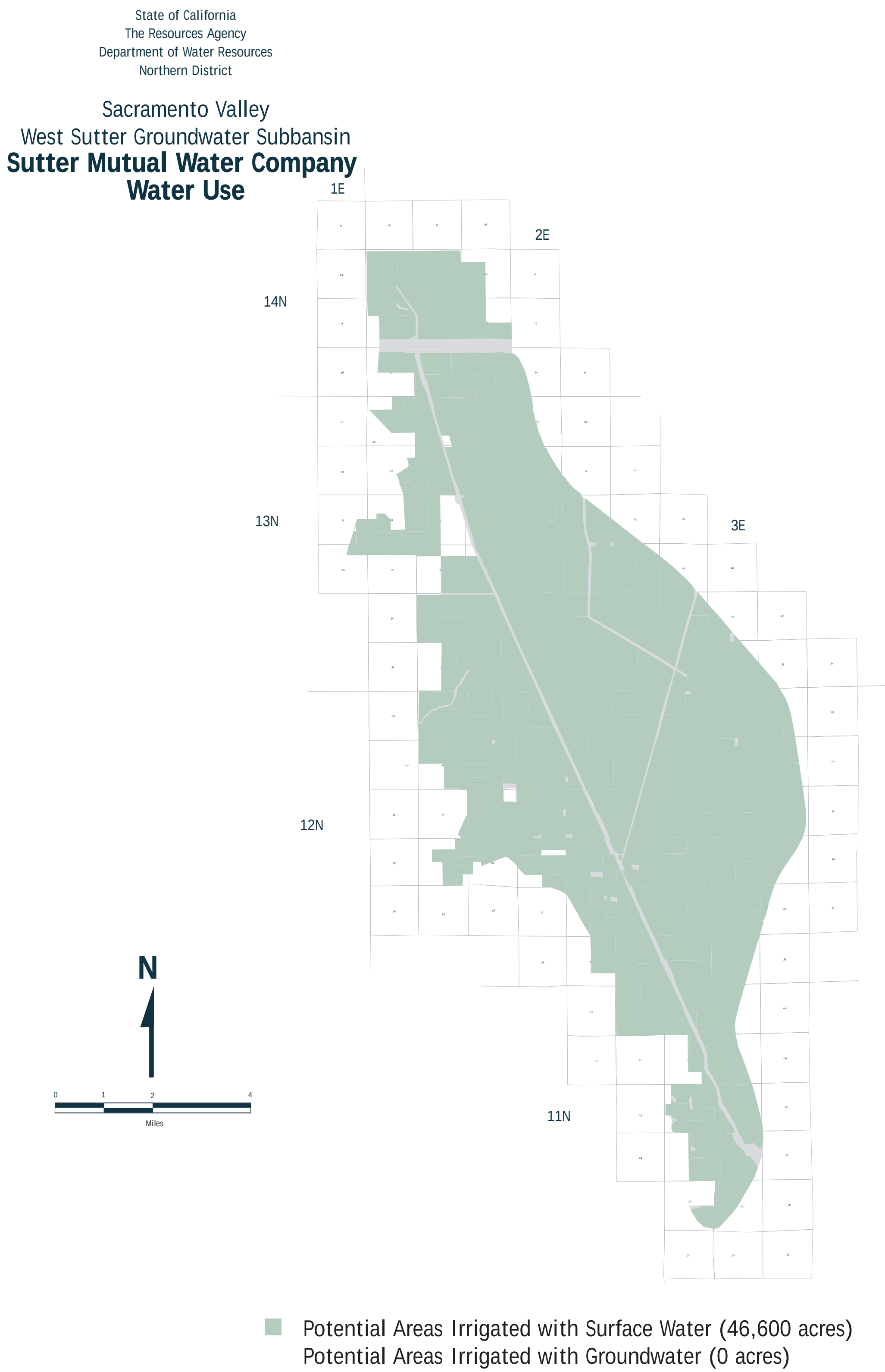
Figure 37
Hydrograph for State Well Number 11N/03E-08N01M in the West Sutter Subbasin and southern SMWC.
Well Use: *Domestic (Possible Unconfined)*



Vertical movement of groundwater is also an important component in the SMWC service area. Vertical movement of saline connate water along the Sutter Basin Fault is believed to be the cause of a large mound of saline water that is in the east-central portion of the SMWC service area. High pressure in the Cretaceous marine sediments has caused the connate water to displace the fresh water in about 2,000 feet of overlying post-Eocene sediments. Theoretically, the pressures are created by inflow of fresh water into Cretaceous sandstone units that have been tilted up and crop out along the Sutter Buttes. The amount of hydraulic head needed to displace the overlying fresh water would be about 260 to 425 feet (Curtin 1971).

Groundwater Extraction. The SMWC service area covers about 51,100 acres within Sutter County. DWR conducted land use surveys for Sutter County in 1990. The survey shows that the net irrigated acreage for SMWC was about 43,400 acres. Based on the 1990 land use survey, the 43,400 net acres were irrigated with surface water. Figure 38 shows general agricultural water use for the SMWC service

Figure 38
Water use map for SMWC



Potential Areas Irrigated with Surface Water (46,600 acres)
Potential Areas Irrigated with Groundwater (0 acres)
Potential Areas Irrigated with Surface Water and Groundwater (0 acres)
Potential Non-Irrigated Areas (~1,100 acres)
Potential Areas Irrigated with Reclaimed Groundwater (0 acres)

Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

area developed from historical land and water use data.

Water use areas delineated in Figure 38 show that about 46,600 acres within the SMWC area have the potential to be serviced by surface water. Figure 38 also shows that there is currently no potential for groundwater irrigation and that about 1,100 acres are non-irrigated.

Well Yield. In 1961, USGS compiled utility pump test records and summarized average well yield data for irrigation wells in the Verona-Knights Landing region (Olmsted 1961). The region covers a 5- to 10-mile strip along both sides of the Sacramento River from the Colusa-Yolo county line south to Sacramento. SMWC extends over much of the northeastern portion of the Verona-Knights Landing area. The well yield estimates developed by USGS extend over large areas, of which the SMWC service area covers only a small portion. Because USGS data are regional and not specific to the SMWC service area, the well yield information should be considered approximate. USGS well yield data are summarized in Table 32.

Table 32
Well yield summary for SMWC

	Verona-Knights Landing
Number of Wells	45
Average Depth	303 ft
Average Yield	740gpm

Approximately 128 Well Completion Reports are filed with DWR for the SMWC service area. Of the 128 reports, only two wells listed well yield data. One well was reported as a domestic well, and one was reported as an irrigation well. The domestic well had a reported yield of 130 gpm, and the irrigation well had a reported yield of 1,000 gpm.

Well Depth. Well depth and well use data for the SMWC service area were collected from Well Completion Reports filed with DWR. A summary of the minimum, maximum, and average well depth, listed by well use, is presented in Table 33.

Table 33
Well depths in SMWC listed according to well use

Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	37	35	326	136
Industrial	1	193	193	193
Municipal	0	-	-	-
Irrigation	6	80	511	318
Other	84	8	1,565	121

About 29 percent of the wells in the SMWC service area were drilled for domestic use, and about 5 percent were drilled for irrigation. One industrial well and no municipal use wells were reported for the SMWC area. The average depth of the domestic wells within the SMWC area is about 136 feet. The average depth of the irrigation wells is about 318 feet.

The well depth data were further analyzed using the cumulative frequency distribution and histogram of well depth for SMWC domestic wells. Figure 39 shows the cumulative frequency distribution and histogram for the depth of domestic wells in the SMWC service area. A total of 38 domestic wells were used in the analysis. The domestic wells ranged in depth from 35 to 326 feet.

The distribution of domestic well data indicates that average well depth is greater than the most frequently occurring well depth.

The cumulative frequency curve of domestic well depth data for SMWC shows that:

50 percent of the irrigation wells are installed to a depth of about 130 feet or less,

10 percent of the irrigation wells are installed to a depth of about 65 feet or less.

The number and distribution of irrigation well data for the SMWC area are too small for an adequate characterization of well depth using statistical methods.

Specific Capacity. In 1961, USGS compiled utility pump test records and reported an average specific capacity of 42 gpm/ft for wells in the Verona-Knights Landing region (Olmsted 1961). SMWC is situated in the northeast portion of the Verona-Knights Landing region. Because USGS data are regional and not specific to the SMWC service area, the specific capacity data from the USGS investigation should be considered approximate.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the SMWC area is about 5 feet. Estimates of groundwater storage capacity assume a maximum aquifer saturation from a uniform depth of 5 feet to the base of fresh water at about 400 feet, a service area of about 51,100 acres, and a specific yield of 5.5 percent (Olmsted 1961). The estimated groundwater storage capacity beneath the SMWC is 1,110 taf. Methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

Groundwater in Storage. Table 34 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. Methodology used to estimate groundwater in storage is discussed in Chapter 1.

Changes in Groundwater in Storage, 1989-99. The estimated spring-to-spring change in groundwater in storage for the SMWC service area is shown in Figure 40. The monitoring well used to estimate changes in groundwater in storage is listed in Figure 39, and its location is shown in Plate 5. This well is within the south-central SMWC service area.

The spring-to-spring groundwater in storage dropped below the 1989 baseline storage level during the drought of the early 1990s. In 1996, spring groundwater in storage again dropped below the 1989 baseline storage level but recovered in 1997 and 1998. The amount of groundwater in storage during spring 1999 is slightly greater than during spring 1989. The methodology used to estimate changes in groundwater in storage is discussed in Chapter 1.

Conjunctive Management Potential. Based on the limited information on the aquifer system, it appears that developing a conjunctive management project in the SMWC service area may

Table 34
Estimated amount of groundwater in storage in SMWC

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	5 feet	1,110 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	550 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	130 feet	350 taf
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	65 feet	170 taf

Figure 39
Cumulative frequency distribution and histogram of domestic well depth within SMWC

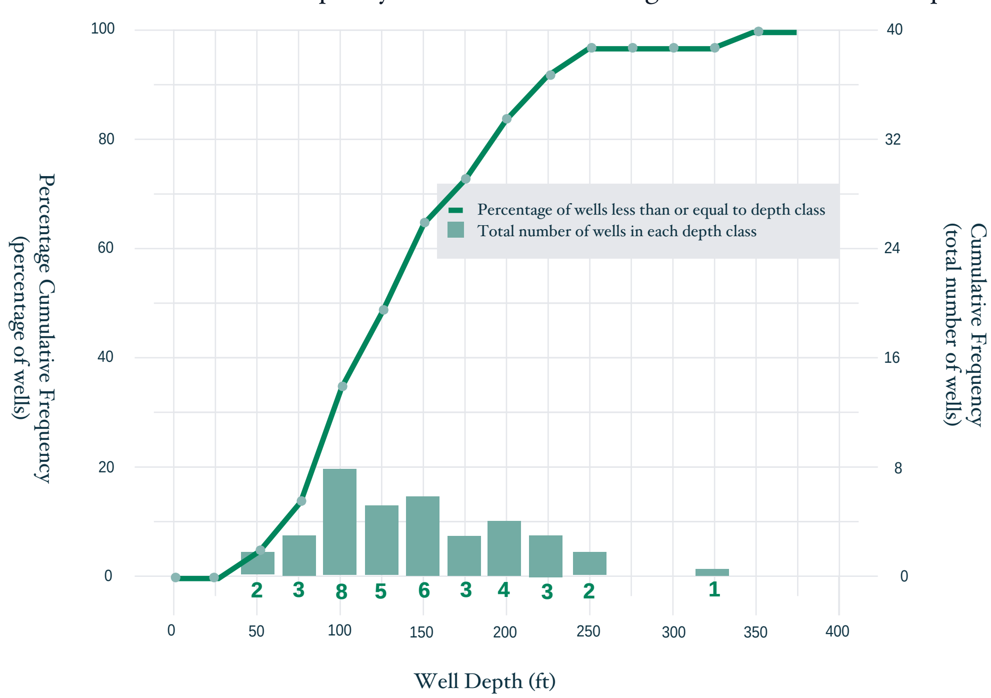
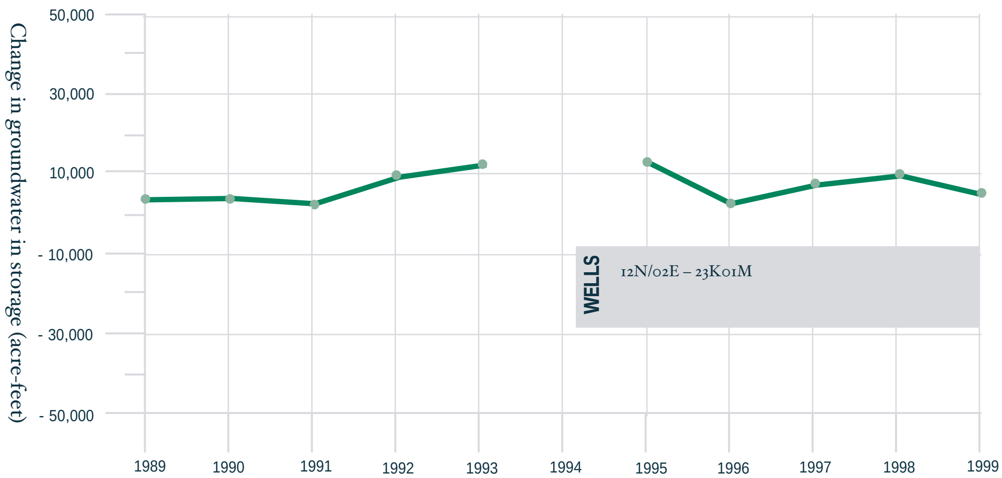


Figure 40
Changes in groundwater in storage in SMWC, 1989-99



prove problematic. The West Sutter Subbasin has widespread shallow saline water, and in some cases this saline water reaches nearly the top of the saturated aquifer. Extracting large volumes of groundwater could cause zones of saline water to move into freshwater portions of the existing aquifer. In addition to the water quality problems, the basin deposits that underlie much of the service area are not productive, and finding adequate recharge areas may be difficult.

Pelger Mutual Water Company

The Pelger Mutual Water Company (PMWC) covers about 3,000 acres in the west-central portion of the West Sutter Subbasin in Sutter County. PMWC is bordered by Sutter Mutual Water Company on the north and east, and by the Sacramento River on the west. Surface water is the primary source of agricultural water in the service area. Similar to SMWC, aquifer productivity and hydrogeology data for the PMWC area are limited. A meaningful analysis of aquifer characteristics in the PMWC service area is not possible due to the lack of site specific data.

Groundwater Levels. DWR is not monitoring groundwater levels within the PMWC service area. The closest groundwater level data are from monitoring wells in the SMWC service area. The well numbers of the two closest wells are State Well Number 12N/02E-09D03M and State Well Number 13N/02E-34M01M. Well 12N/02E-

09D03M is an observation well located about 2 miles southeast of the PMWC service area. This well has a discontinuous period of record dating from 1958 to 1964. The other well, 13N/02E-34M01M, is a shallow irrigation well located about 2 miles east of the southeastern PMWC service area. Groundwater levels in this well were monitored semi-annually from 1958 through 1980. Table 35 lists the annual fluctuation of groundwater levels during normal and drought years for these two monitoring wells. The locations of the monitoring wells are illustrated in Plate 5.

Table 35
Annual fluctuation of groundwater levels for wells within SMWC and adjacent to PMWC

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Annual GW Fluctuation: Drought Years (feet)
12N/02E-09D03M	Observation	—	2 – 4	—
13N/02E-34M01M	Ind./stock	Unconfined	4 – 6	5 – 8

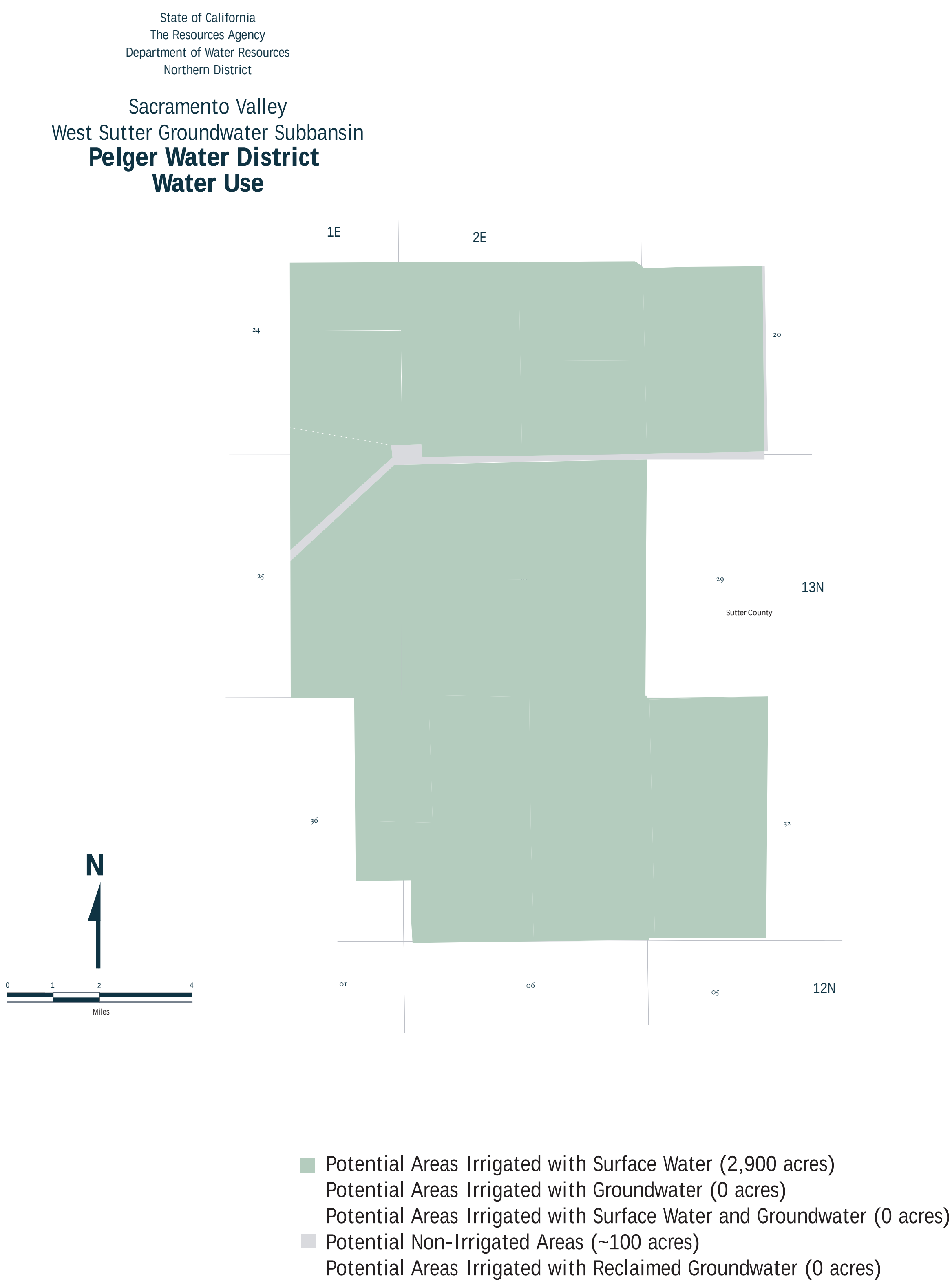
Note: — indicates data was not available

Annual groundwater fluctuation for the unconfined portion of the aquifer is 4 to 6 feet during normal precipitation years and up to 8 feet during drought years. The construction of State Well Number 12N/02E-09D03M is unknown, and it is unclear in which aquifer system it is installed. Nearby water level data are unavailable for the semi-confined or confined portion of the aquifer system beneath PMWC.

Groundwater Movement. The general movement of groundwater in PMWC is to the southeast, toward SMWC at a gradient of about 2.3 feet per mile. The direction and gradient of groundwater flow are shown in Plates 3 and 4.

Groundwater Extraction. The PMWC service area covers about 3,000 acres within Sutter County. DWR conducted land use surveys for Sutter County in 1990. The surveys show that the net irrigated acreage for PMWC was about 2,900 acres. Although PMWC owns several irrigation wells, the 1990 data show that all of the 2,900 net acres were irrigated with surface water. Figure 41 shows general agricultural water use for the PMWC service area developed from historical land and water use data.

Figure 41
Water use map for PMWC



Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

All of the 2,900 irrigated acres within PMWC have the potential to be serviced by surface water. The district also owns several production wells that are not associated with a particular field, but are capable of pumping into the distribution system. Figure 41 lists the potential acreage irrigated by groundwater as zero. However, several hundred acres could likely be serviced by groundwater.

Historically, PMWC has pumped groundwater to serve as a supplemental supply during times of imposed surface water deficiencies, such as during the 1991 Drought Water Bank.

Well Yield. In 1961, USGS compiled utility pump test records and summarized average well yield data for irrigation wells in the Verona-Knights Landing region (Olmsted 1961). The Verona-Knights Landing region covers a 5- to 10-mile strip along both sides of the Sacramento River from the Colusa-Yolo county line, south to Sacramento. PMWC extends over a portion of the northeastern Verona- Knights Landing region. The well yield estimates developed by USGS extend over large areas, of which the PMWC service area covers only a small portion. Because USGS data are regional and not specific to the PMWC service area, the well yield information should be considered an approximation of well yield conditions in the PMWC service area. Well yield data from USGS are summarized in Table 36.

Table 36
Well yield summary for PMWC

	Verona-Knights Landing
Number of Wells	45
Average Depth	303 ft
Average Yield	740gpm

Four Well Completion Reports are filed with DWR for the PMWC service area. None of these reports list well yield information.

Well Depth. Well depth and well use data for the PMWC service area were collected from Well Completion Reports filed with DWR. A summary of the minimum, maximum, and average well depth, listed by well type, is presented in Table 37.

Table 37
Well depths in PMWC according to well use

Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	0	-	-	-
Industrial	1	55	55	55
Municipal	0	-	-	-
Irrigation	2	520	632	576
Other	1	17	17	17

Table 37 shows that roughly one industrial well and two irrigation wells are recorded for the PMWC service area. The average depth of the two irrigation wells is 576 feet.

The number of wells and distribution of well data for the PMWC area are too small for an adequate characterization of well depth using statistical methods.

Specific Capacity. In 1961, USGS compiled utility pump test records and reported an average specific capacity of 42 gpm/ft for wells in the Verona-Knights Landing region (Olmsted 1961). PMWC is situated in the northeast portion of the Verona-Knights Landing region. Because USGS data are regional and not specific to the PMWC service area, USGS specific capacity data should be considered an approximation of actual conditions.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the PMWC area is about 5 feet. Estimates of groundwater storage capacity assume a maximum aquifer saturation from a uniform depth of 5 feet to the base of fresh water at about 900 feet, a service area of about 3,000 acres, and a specific yield of 5.5 percent (Olmsted 1961). The estimated groundwater storage capacity beneath PMWC is 150 taf. Methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

Groundwater in Storage. Table 38 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. Methodology used to estimate groundwater in storage is discussed in Chapter 1.

Table 38
Estimated amount of groundwater in storage in PMWC

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	5 feet	150 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	32 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	insufficient data	insufficient data
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	insufficient data	insufficient data

Changes in Groundwater in Storage, 1989-99. Estimates of changes in groundwater in storage for PMWC were not calculated because of a lack of groundwater level monitoring data.

Conjunctive Management Potential. Although PMWC has participated in previous water transfers, it appears that developing a long-term conjunctive management project in this service area may prove problematic. East of the PMWC service area, the Sutter Mutual Water Company service area has problems associated with the upwelling of shallow saline water. Extracting large volumes of groundwater in this area could cause poor quality water to move into freshwater portions of the existing aquifer. Agricultural use of existing wells typically requires mixing of groundwater with surface water to lower the total dissolved solids. Similar to the Sutter Mutual service area, basin deposits that underlie much of the PMWC service area are not very productive or conducive to recharge.

Sacramento Valley Groundwater Basin, North American Subbasin

The North American Subbasin covers about 550 square miles in the southeast corner of the Sacramento Valley. The North American Subbasin is bounded by the American River on the south, the Feather and Sacramento rivers on the west, the Bear River on the north, and metamorphic rock of the Sierra Nevada foothills on the east. Although these rivers provide substantial recharge to the subbasin, extensive groundwater extraction in the north Sacramento area is contributing to perennial depressions of groundwater levels in the southern portion of the subbasin. The only Sacramento River Settlement Contractor within the North Sacramento Subbasin is Natomas Central Mutual Water Company. The North American Subbasin, along with the Sacramento River Settlement Contractor areas, is shown in Plate 1.

The freshwater aquifer system in the North American Subbasin is composed of Tertiary age volcanic rock and younger continentally-derived sediments. The oldest fresh-water-bearing formation in the subbasin is the Mehrten Formation.

The Mehrten Formation unconformably overlies marine and brackish-water sediments of Eocene age. The upper surface of the formation is deeper in the northern portion of the subbasin and thins toward the south. The formation can be divided into two units. The first unit consists of gray to black andesitic sands, and the second unit consists of dense, hard, gray tuff breccia. The sands are fluvial deposits derived from andesitic source rock in the Sierra Nevada and contain lenses of sand and gravel, in addition to cobbles and boulder material. The sand and gravel lenses are often interbedded with blue and brown clay. The second unit is composed of angular andesite blocks and fragments in a cemented matrix of andesitic devitrified lapilli and ash derived from volcanism within the Sierra Nevada. Where present, the tuff breccia yields little water to wells and acts as a confining layer in the subsurface.

Unconformably overlying the Mehrten Formation are the Laguna Formation and the Turlock Lake Formation. These units are exposed in the dissected uplands along the eastern margin of the basin and dip westward beneath the land surface toward the axis of the valley. The formations consist of a heterogeneous mixture of tan to brown interbedded silt, clay, and sand, with occasional gravel lenses. Gravel lenses are poorly sorted and have low permeability. Wells drawing from the Laguna Formation sands and gravels produce significant quantities of groundwater. The combined thickness of the two units in the study area is probably less than 200 feet.

Overlying the Laguna and Turlock formations are terrace deposits of the Riverbank and Modesto formations. The maximum combined thickness of these units in this area of the Sacramento Valley is 50 to 75 feet. Overall permeability is moderate with occasional coarse-grained zones of high permeability.

Flood basin deposits and alluvium are the youngest geologic units in the study area. The most widespread exposures occur along the western and northern margins, adjacent to, and within, the active channels of the Bear and Feather rivers. Maximum thickness of the flood basin deposits is 100 feet.

Natomas Central Mutual Water Company

The Natomas Central Mutual Water Company (NCMWC) services about 50,800 acres in the western portion of the North American Subbasin. Covering a portion of Sacramento and Sutter counties, the NCMWC is bordered on the north by the Natomas Cross Canal, on the south and west by the Sacramento River, and on the east by the Natomas East Main Drain.

Groundwater Levels. DWR monitors groundwater levels in 16 wells within the NCMWC service area. The groundwater level-monitoring grid consists of a mixture of domestic, irrigation, and industrial wells. Table 39 lists NCMWC wells that are currently being monitored, along with the annual fluctuation of groundwater levels during normal and drought years. Monitoring wells are shown in Plate 5.

Historical groundwater level data for the NCMWC monitoring wells indicate that the annual fluctuation of groundwater levels in the unconfined portion of the aquifer system averages between 2 and 6 feet during normal precipitation years, and up to 10 feet during

Table 39
Annual fluctuation of groundwater levels within NCMWC

State Well Number	Well Use	Aquifer System	Annual GW Fluctuation: Normal Years (feet)	Annual GW Fluctuation: Drought Years (feet)
09N/04E-01R01M	Domestic	Semi-confined	4 - 6	10 - 16
09N/04E-10C01M	Irrigation	Unconfined	2 - 3	3 - 4
09N/04E-11E01M	Unknown	Unconfined	2 - 4	4 - 6
09N/04E-22E01M	Domestic	Unconfined	2 - 4	4 – 8
09N/04E-27F01M	Irrigation	Semi-confined	2 - 4	10 – 18
10N/03E-35A01M	Irrigation	Semi-confined	3 - 6	8 – 12
10N/04E-02K01M	Irrigation	Unconfined	3 – 5	5 – 7
10N/04E-21B02M	Irrigation	Unconfined	1 - 2	2 – 3
10N/04E-23A01M	Industrial	Unconfined	3 - 5	3 – 5
10N/04E-24B01M	Irrigation	Unconfined	1 - 2	2 – 3
10N/04E-34A02M	Unknown	Semi-confined	3 - 5	8 – 10
10N/04E-36B01M	Irrigation	Unconfined	3 - 4	4 – 6
11N/04E-09D02M	Domestic	Unconfined	3 - 6	6 – 10
11N/04E-19E02M	Domestic	Semi-confined	3 - 5	10 – 25
11N/04E-33J01M	Irrigation	Composite	2 - 3	—
11N/04E-34N01M	Domestic	Composite	3 - 4	3 – 16

Note: — indicates data was not available

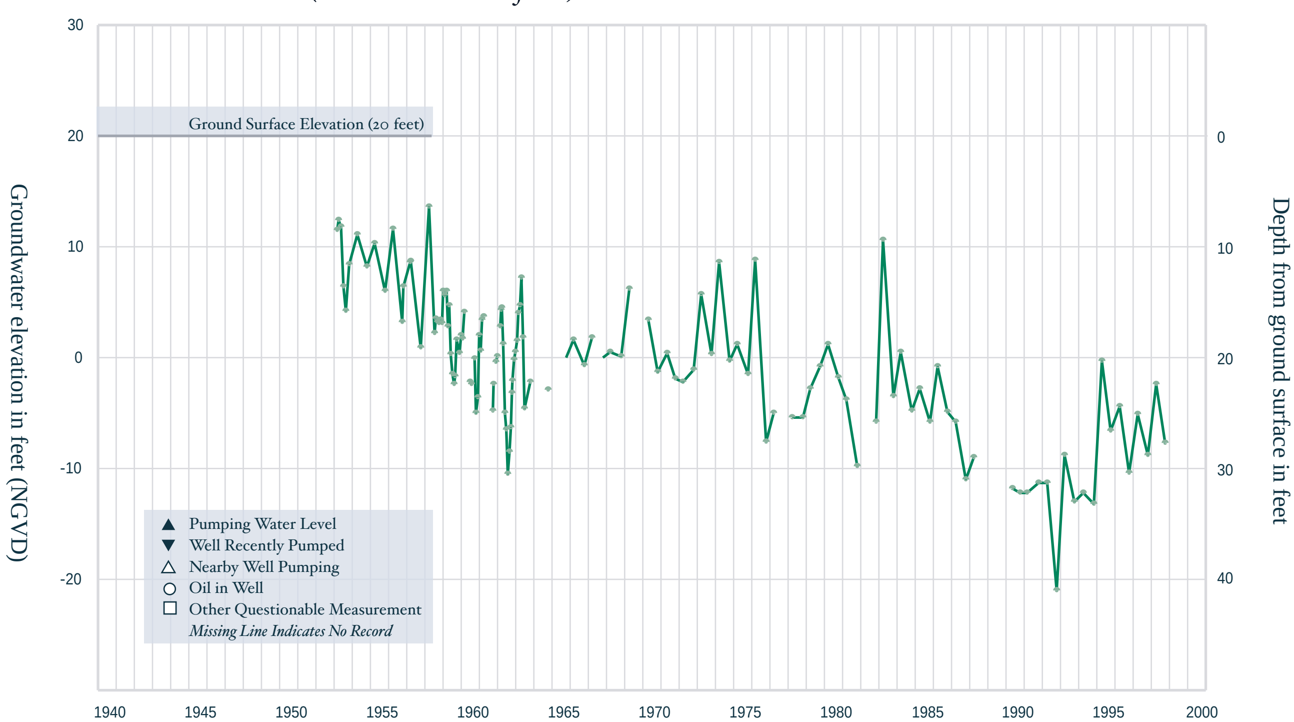
periods of drought. Annual fluctuation of groundwater levels in the semi-confined portion of the aquifer system is typically larger, with an average of 3 to 6 feet during normal years and up to 25 feet during drought years. Wells located near recharge sources typically show less of an annual change in groundwater levels.

Figure 42 is a hydrograph for State Well Number 09N/04E-01R01M, a shallow domestic well with groundwater levels that are representative of the unconfined portion of the aquifer system in the southeastern NCMWC area. Figure 42 illustrates the perennial drawdown in groundwater levels that occurs in this area due to municipal and industrial groundwater extraction in the north Sacramento area.

Groundwater Movement. The groundwater flow in NCMWC is influenced by groundwater extraction in the north Sacramento area that contributes to a pumping depression in the southern portion of the North American Subbasin. The groundwater level depression causes groundwater in the southern two-thirds of the district to move in a south-southeasterly direction, toward the center of the depression, at a gradient of about 10 feet per mile. In the extreme northern portion of the district, groundwater flows in a more southwesterly direction toward the Sacramento River at a gradient of about 4 feet per mile. The gradient and direction of groundwater movement are shown in Plates 3 and 4.

Groundwater Extraction. The service area for NCMWC covers about 50,800 acres over portions of Sutter and Sacramento counties. DWR conducted land use surveys for Sutter County in 1990 and for Sacramento County in 1998. These surveys show that the net irrigated acreage for NCMWC was about 32,300 acres. Of the 32,300 acres in production, approximately 29,500 acres were irrigated with surface

Figure 42
Hydrograph for State Well Number 09N/04E-01R01M in the North American Subbasin and southeastern NCMWC
Well Use: *Domestic (Probable Semi-Confined)*



water, and about 2,800 acres were irrigated with groundwater. The amount of groundwater applied to the 2,800 acres is estimated at 15,000 af. Figure 42 shows general agricultural water use for the NCMWC service area developed from historical land and water use data.

About 45,000 acres within NCMWC have the potential to be serviced by surface water, and 2,800 acres have the potential to be serviced by groundwater. Based on the water use map, no fields have the potential to be serviced by a mixed water source. Approximately 2,700 acres within the NCMWC service area are non-irrigated.

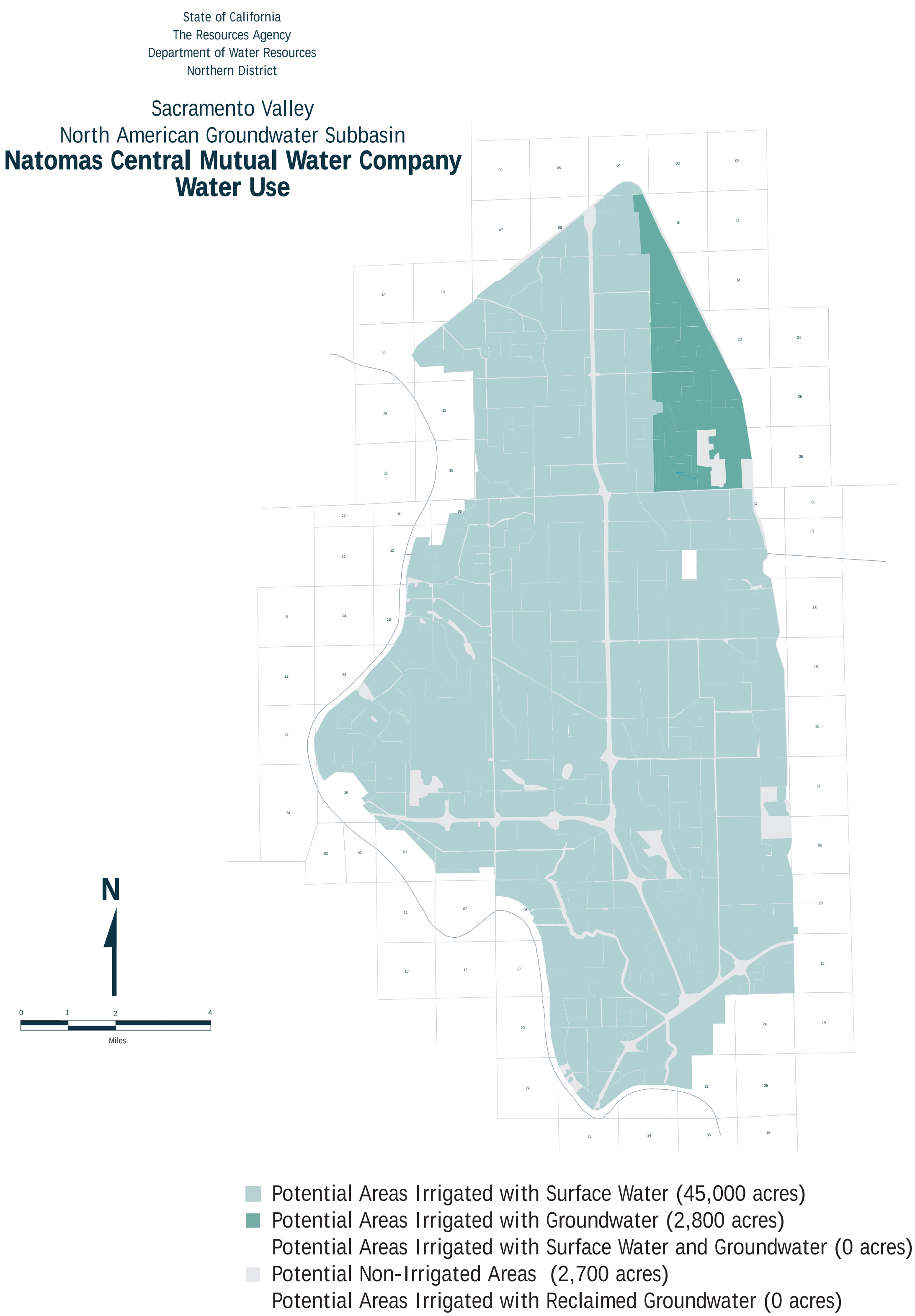
Well Yield. In 1961, USGS compiled utility pump test records and summarized average well yield data for irrigation wells in the Verona-Knights Landing and North Sacramento-Fair Oaks regions (Olmsted 1961). The Verona-Knights Landing region covers a 5- to 10-mile strip along both sides of the Sacramento River from the Colusa-Yolo county line, south to Sacramento. The North Sacramento-Fair Oaks region extends from the Sutter-Sacramento county line to the American River. The NCMWC service area extends over much of the southeastern portion of the Verona-Knights Landing region and the western North Sacramento-Fair Oaks region. The well yield estimates developed by USGS extend over large areas, of which the NCMWC service area covers a small portion. Because USGS data are regional and not specific to the NCMWC, the well yield information should be considered an approximation of well yield conditions in the NCMWC service area. The well yield data from USGS are summarized in Table 40.

Table 40
Well yield summary for the NCMWC

	Verona-Knights Landing	N. Sacramento-Fair Oaks
Number of Wells	45	54
Average Depth	303 ft	334 ft
Average Yield	740 gpm	250 gpm

There are 94 Well Completion Reports for irrigation wells filed with DWR for the NCMWC service area. Of the 94 well completion reports, 27 list well yield. The average well yield for the irrigation wells is 1,625 gpm. There are also two industrial and three municipal

Figure 43
Water use map for NCMWC



Note:
Water use areas are classified based on existing facilities for water delivery, and represent the potential for water application of the type indicated.
Water use areas do not represent specific areas of application for any single year.
Water use areas are digitized from 7.5 minute USGS Quadrangles using DWR land use survey techniques.
Water use areas are presented as net irrigated acreage. Net irrigated acreage represents a 5% reduction from gross acreage to account for roads, ditches, canals, etc.
Water use area should be considered approximate.

wells that list well yield data on the Well Completion Reports. The average well yield from these five wells is 1,340 gpm.

Well Depth. Well depth and well use data for the NCMWC area were collected from Well Completion Reports filed with DWR. A summary of the minimum, maximum, and average well depth, listed by well use, is presented in Table 41.

Table 41
Well depths in NCMWC listed according to well use

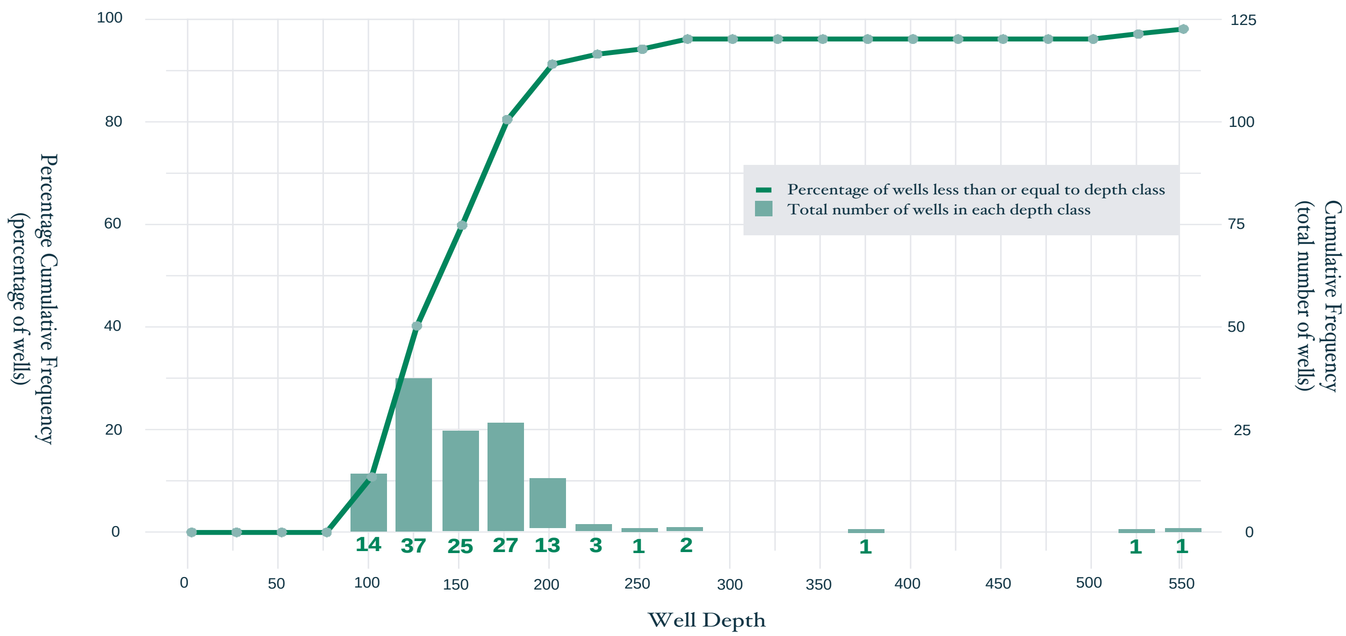
Type of Use	Number of Wells	Minimum Depth (ft)	Maximum Depth (ft)	Average Depth (ft)
Domestic	125	80	540	149
Industrial	8	120	600	378
Municipal	8	30	515	308
Irrigation	94	76	1,025	313
Other	61	11	675	132

About 42 percent of the wells in NCMWC were drilled for domestic use, and 32 percent were drilled for irrigation. Municipal and industrial use wells account for only 5 percent of the total number of wells. The average depth of the domestic wells within NCMWC is about 149 feet, while the higher-producing irrigation, industrial and municipal wells tend to be significantly deeper with average depths of 313 feet for irrigation, 378 feet for industrial, and 308 feet for municipal wells.

The well depth data were further analyzed using the cumulative frequency distribution and histograms of well depth for domestic and irrigation wells. Figure 44 is a cumulative frequency distribution curve and histogram for the depth of domestic wells in the NCMWC service area. A total of 125 domestic wells were used in the analysis. The domestic wells ranged in depth from 80 to 540 feet.

The distribution of the domestic well depth data is skewed slightly toward shallower well depths. The distribution of domestic well data indicates that the average well depth is deeper than the most frequently occurring well depth.

Figure 44
Cumulative frequency distribution and histogram of domestic well depth within NCMWC



The cumulative frequency curve of domestic well depth data for NCMWC shows that:

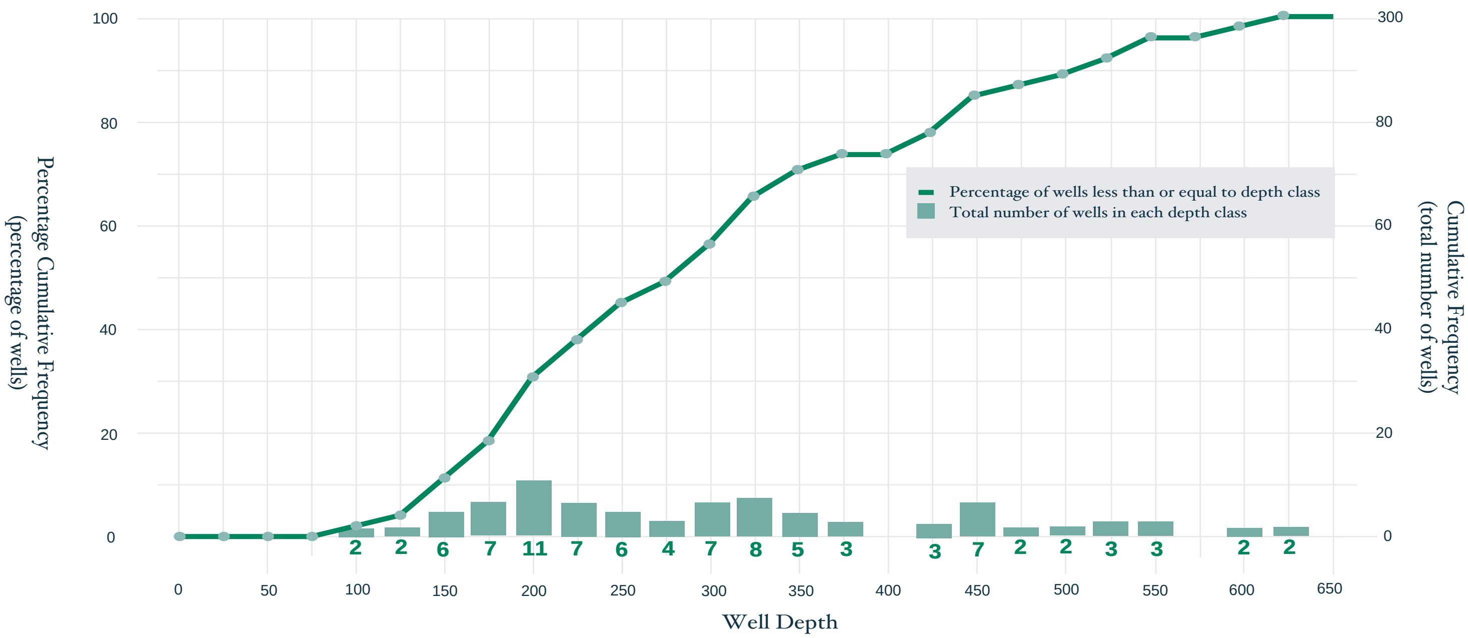
50 percent of the domestic wells are installed to a depth of about 140 feet or less,

10 percent of the wells are installed to a depth of about 100 feet or less.

Figure 45 shows the cumulative frequency distribution and histogram for the depth of irrigation wells in the NCMWC service area. A total of 94 wells were used in the analysis. The irrigation wells ranged in depth from 76 to 1,025 feet.

The distribution of irrigation well depth data is spread over a large range and skewed slightly toward shallow well depths. The distribution of the irrigation well data indicates that the average well depth is deeper than the most frequently occurring well depth.

Figure 45
Cumulative frequency distribution of irrigation well depth within NCMWC



The cumulative frequency curve of irrigation well depth data shows that:

> 50 percent of the irrigation wells are installed to a depth of about 280 feet or less,
>
> 10 percent of the irrigation wells are installed to a depth of about 150 feet or less.

Specific Capacity. In 1961, USGS compiled utility pump test records and reported an average specific capacity of 42 and 21 gpm/ft for wells near the Verona-Knights Landing and North Sacramento-Fair Oaks regions (Olmsted 1961). NCMWC extends over much of the southeastern portion of the Verona-Knights Landing region and the western North Sacramento-Fair Oaks region. Because USGS data are regional and not specific to the NCMWC service area, the specific capacity data should be considered an approximation of actual conditions.

Groundwater Storage Capacity. Estimates indicate that the average depth to groundwater within the NCMWC area is about 15 feet. Estimates of groundwater storage capacity assume a maximum aquifer saturation from a uniform depth of 15 feet to the base of fresh water at about 1,400 feet, a service area of about 50,800 acres, and a specific yield of 4.6 percent (Olmsted 1983). Based on these assumptions, the estimated groundwater storage capacity beneath the NCMWC area is 3,240 taf. The methodology used to estimate groundwater storage capacity is discussed in Chapter 1.

Groundwater in Storage. Table 42 shows the estimated amount of groundwater contained within a given saturated thickness. Estimates are based on the aquifer assumptions presented above. The methodology used to estimate groundwater in storage is discussed in Chapter 1.

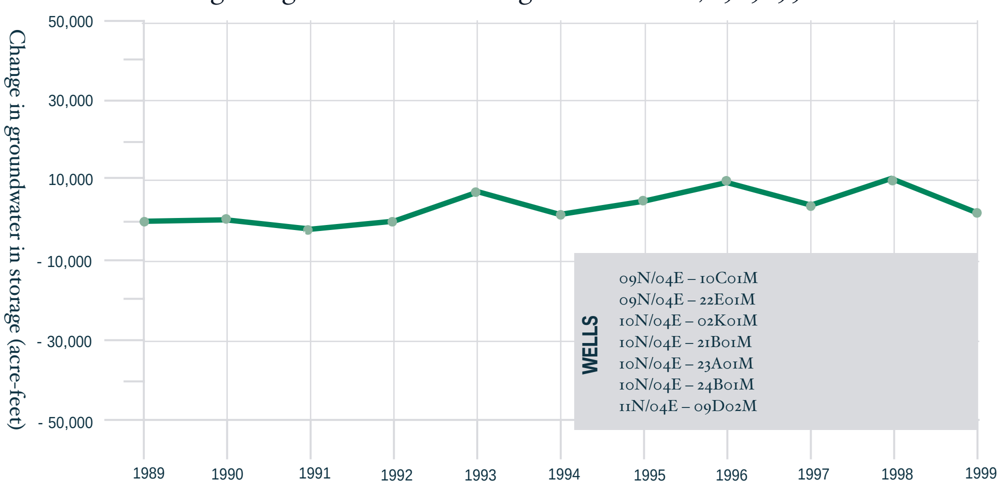
Changes in Groundwater in Storage, 1989-99. The estimated spring-to-spring change in groundwater in storage for the NCMWC service area is shown in Figure 46. The seven monitoring wells used to estimate the changes in groundwater in storage are listed in Figure 46, and their locations are shown in Plate 5. These wells are distributed fairly evenly within the district.

Table 42
Estimated amount of groundwater in storage in NCMWC

Saturated Thickness	Corresponding Depth of Groundwater Level	Estimated Amount of Groundwater in Storage to the Corresponding Depth
Total groundwater in storage	15 feet	3,240 taf
A uniform lowering of groundwater levels to 200 feet	200 feet	430 taf
A uniform lowering of groundwater levels to a depth where 50% of the irrigation wells would be dewatered	280 feet	620 taf
A uniform lowering of groundwater levels to a depth where 10% of the irrigation wells would be dewatered	150 feet	315 taf

Figure 46 shows that the spring-to-spring groundwater in storage dropped below the 1989 baseline storage level during the drought of the early 1990s, and then recovered through the mid- to late 1990s. Figure 46 also shows that the amount of groundwater in storage during spring 1999 is slightly greater than during spring 1989. The methodology used to estimate changes in groundwater in storage is discussed in Chapter 1.

Figure 46
Changes in groundwater in storage in NCMWC, 1989-99



Conjunctive Management Potential. In 1997, DWR completed a comprehensive conjunctive use feasibility investigation for the American Basin. Conclusions from this investigation indicate that conjunctive use in the American Basin is technically and economically feasible. Overall, the conjunctive use potential of the proposed project was estimated at 55,000 acre-feet. About two-thirds of the NCMWC service area was included in the 1997 study area. However, additional studies are still needed to help determine the optimum approach to conjunctive use operations, including methods of groundwater recharge and recovery of stored groundwater. Studies are also needed to ensure compliance with the local groundwater management plans and ordinances.

Typically, in-lieu recharge would be the preferred method of aquifer recharge in this area. In-lieu recharge requires the delivery of surface water to areas irrigated by groundwater. The stored groundwater would best be recovered through groundwater substitution using existing wells or newly installed recovery wells.

Groundwater Quality

Groundwater Quality

The analysis of groundwater quality in the Sacramento Valley is based primarily on existing data collected by DWR and a generalized characterization by USGS. Most of DWR's groundwater quality monitoring wells consist of domestic wells that are of shallow or intermediate depth. Although additional groundwater quality data were collected from published and unpublished investigations, little water quality information is available for deep irrigation wells. As a result, much of the data presented in this report characterize the water quality of the unconfined or semi-confined areas of the aquifer system. The existing water quality data from deep wells are insufficient to characterize the confined aquifer system at the subbasin or the settlement contractor service area level. If conjunctive management in the Sacramento Valley is to increase, developing and implementing a more comprehensive water quality monitoring plan is necessary to characterize and to identify potential impacts to neighboring groundwater users.

This chapter provides background information on general water quality characterization and constituents, regional groundwater quality, and estimates of groundwater quality for each SRSC service area. The water characterizations presented in this report are estimates based only on available data. Water quality has not been evaluated in terms of drinking water standards and does not include any analysis for the presence of volatile organic compounds. This chapter is divided into the following subsections:

- Characterization of Groundwater Quality
- Water Quality Impacts
- Regional Groundwater Quality Assessment
- Groundwater Quality Assessment of SRSC Service Areas

Characterization of Groundwater Quality

Characterization, or typing, of groundwater identifies the groundwater chemistry according to the relative abundance of dominant cations and anions in their chemical milliequivalents per liter. For example, a groundwater sample that is typed as sodium bicarbonate has at least 50 percent sodium as the principal cation and at least 50 percent bicarbonate as the principal anion in chemical milliequivalents. If no cation or anion comprises 50 percent or more of the general water chemistry, then the water type would be considered transitional and would be typed by the first and second most dominant ions, such as calcium magnesium bicarbonate or sodium chloride sulfate.

In general, groundwater chemistry is a function of the geology of the recharge source area and the aquifer system. Similar types of groundwater quality are associated with similar types of subsurface geology. A dominating factor in determining the geochemistry of groundwater is the ability of the aquifer sediments to undergo cation exchange with the water. Fine-grained sediments such as clay have a greater ability to capture ions from groundwater as it moves through the aquifer system. As an example, magnesium, followed by calcium, has a stronger attraction than sodium to these fine-grained sediments. The groundwater will lose magnesium, followed by calcium, and gain equivalent amounts of sodium as it continues along a horizontal and/or vertical flow path. Thus, as groundwater moves through the system, it becomes less concentrated with magnesium and calcium, and more concentrated with sodium. As a result, the geochemistry of older and deeper flowing groundwater or groundwater in fine-grained sediments is often characterized as sodium bicarbonate.

Water Quality Impacts

Agricultural use of poor quality groundwater can result in a number of crop-related impacts. Some typical impacts include:

decreased availability of water due to a buildup of salts in the root zone,

reduced rate of infiltration because of excessive ion exchange and collapse of surface soil structure, and

general plant toxicity due to the application of poor agricultural quality groundwater.

Some of the more common geochemical groundwater constituents are presented below along with a discussion of their potential agricultural-related impacts.

Total Dissolved Solids

Total dissolved solids (TDS) above 500 mg/L can be undesirable for irrigation water under certain application conditions. Elevated TDS can become more pronounced where low-volume irrigation practices are used on low-permeability soils in areas with high evapotranspiration rates, resulting in increased soil salinity.

Chloride

Chlorides are one of several constituents that contribute to the overall salinity of irrigation water. Because the salinity usually impairs crops before the concentration of chloride in the soil can reach harmful levels, chloride is generally not harmful to crops. However, excessive chloride can be harmful to some fruit crops where irrigation practices result in accumulation of salts in the root zone. Water with chloride concentrations in excess of 106 mg/L can cause damage to citrus, stone fruit, and almond orchards when applied by sprinklers (DWR 1997). Under other irrigation methods, a permissible chloride concentration for most plants is 700 mg/L (Fogelman 1978).

Sodium

Excess concentrations of sodium in irrigation water can damage crops by causing leaf burn or by altering the soil structure, infiltration, and permeability (Fogelman 1978).

The potential for sodium toxicity from applied groundwater depends on the application method and the concentration of sodium and of other elements within the groundwater. Application of groundwater with sodium concentrations above 69 mg/L may be detrimental to some crops if applied by sprinklers. Where irrigation water contains elevated concentrations of sodium in relation to calcium, damage to some crops, including deciduous fruits, may occur earlier.

Indirect damage from application of irrigation water having excessive sodium typically occurs when the concentration of sodium exceeds 50 percent of the total cations. This type of indirect damage is due to a breakdown of a wetted soil structure and a subsequent decrease in permeability and root penetrability.

In 1954 the sodium-adsorption-ratio (SAR) method was developed to measure the sodium hazard of irrigation water. For example, a SAR greater than 3 can potentially injure some crops. Combining the SAR value with measurements of conductivity, the U.S. Salinity Laboratory developed a classification system to determine the suitability of water for irrigation. This system was also used to determine the degree of salinity and sodium hazard. Waters were classified by an alpha-numeric scheme such as C1-S1 to illustrate the degree of hazard. This classification system is summarized in Table 43.

Table 43
Salinity and sodium hazard classification

Salinity	Hazard	Sodium	Hazard
C1	Low	S1	Low
C2	Medium	S2	Medium
C3	High	S3	High
C4	Very High	S4	Very High

Based on these criteria, groundwater having a classification of C2-S3 would be a medium salinity hazard and a high sodium hazard.

Bicarbonate

At concentrations greater than 175 mg/L, alkalinity, expressed as bicarbonate, has the potential to negatively impact rice production by causing increased algae production. Highly alkaline waters may lead to increased algal growth by countering the effects of copper sulfate commonly applied to inhibit algal growth, resulting in additional application and higher costs.

Boron

Irrigation water with boron concentrations above 0.5 mg/L may be detrimental to some sensitive crops. Symptoms of boron toxicity can be detected in sensitive plants at concentrations between 0.5 and 0.75 mg/L. Semi-tolerant crops show damage when boron concentrations reach 2.0 to 4.0 mg/L. With concentrations greater than 4.0 mg/L, continuous use of boron-contaminated irrigation water will result in poor production of most crops.

Arsenic

Arsenic concentrations as low as 0.5 mg/L have been found to affect some species of citrus. The USEPA recommends a maximum arsenic concentration of 0.1 mg/L for irrigation water intended for continuous use on all types of soil.

Manganese

Irrigation water containing manganese at concentrations above 0.2 mg/L may cause damage to some crops, especially in acidic soils.

Regional Groundwater Quality Assessment

The findings in this section are presented at the regional and subbasin level. Analysis of groundwater quality data at the SRSC level is provided in the section titled "Groundwater Quality Assessment by SRSC Service Area."

Redding Groundwater Basin

In 1993, USGS evaluated the general water quality of the Redding Groundwater Basin (Pierce 1993). The report concluded that, for the majority of the basin, the quality of groundwater was considered good to excellent for most uses. Areas of poor quality groundwater are largely limited to the margins of the basin. In these areas, shallow wells within marine sedimentary rock of the Great Valley Sequence tend to have high salinity levels. For the central portions of the basin, the groundwater geochemistry is characterized as magnesium-calcium bicarbonate.

Sacramento Valley Groundwater Basin

Water quality north of the of the Sutter Buttes is generally characterized as a calcium-magnesium bicarbonate or a magnesium-calcium bicarbonate water. Isolated areas may contain sodium bicarbonate, calcium bicarbonate, and magnesium bicarbonate water types. South of the Sutter Buttes, water quality is characterized as sodium bicarbonate, sodium-calcium bicarbonate, and calcium-sodium bicarbonate water types. Groundwater in the region of T13N/R01W extending to T13N/R02E is characterized as a calcium-magnesium bicarbonate or magnesium-calcium bicarbonate water type similar to areas north of the Sutter Buttes (Fogelman 1978).

Sulfate concentrations greater than 50 mg/L are identified west of the Sutter Buttes in the region extending from the northern half of T14N/R02W to the southern portion of T17N/R02W and also in the region of Knights Landing, which is to the southeast. Boron concentrations greater than 0.75 mg/L have been identified in the region of Knights Landing (Fogelman 1978).

Colusa Subbasin

In 1990, DWR evaluated water quality for the Colusa Subbasin (DWR 1990). Results of the evaluation concluded the following:

Water quality problems exist in some portions of the subbasin and are most likely associated with leaching of alkaline soils.

The overall quality of groundwater is considered good to excellent for most agricultural purposes.

The overall quality of groundwater is often poor for municipal purposes.

In 1976, USGS investigated water quality in the Tehama-Colusa Canal service area (Bertoldi 1976). The results are summarized as follows:

In the southern part of the subbasin, the USGS investigation found that groundwater in the vicinity of Williams, College City, and Zamora could have boron concentrations that pose a hazard to sensitive crops.

Within the region lying south of Williams and north of Zamora are pockets of chloride concentrations ranging from 50 to 100 mg/L and, in some areas, at concentrations greater than 250 mg/L. The dissolved solids concentration is generally higher for the same region.

Sulfate concentrations in the vicinity of Williams range from 51 to 150 mg/L. The concentration of dissolved solids in the same area and in the vicinity of College City are greater than 500 mg/L.

West Butte Subbasin

In 1984, USGS conducted an investigation to evaluate the geochemical changes in groundwater quality with depth for State Well Number 19N/01W-32G along the western part of the subbasin (Hull 1984). Geochemical analyses identified concentrations of bicarbonate, sulfate, chloride, nitrate-N, boron, calcium, magnesium, and sodium at each depth interval between 80 and 595 feet (Hull 1984). Results of the analyses at various depth intervals indicated that:

- concentrations of dissolved solids increased with depth from 276 to 526 mg/L,
- concentrations of bicarbonate decreased with depth from 210 to 110 mg/L,
- decreased concentrations of magnesium with depth was balanced by a relative increase in sodium,
- concentrations of sodium increased with depth from 62 and 160 mg/L,
- concentrations of chloride increased with increasing depth from 22 to 230 mg/L, and
- concentrations of calcium remained about the same with increasing depth.

West Sutter Subbasin

Groundwater quality analyses of the West Sutter Subbasin indicate areas with high concentrations of dissolved solids, sodium, chloride, bicarbonate, potassium, boron, fluoride, iron, manganese, and arsenic. In addition, high salinity values have been recorded for much of the groundwater in the upper 400 feet of the aquifer system in the southern portion of the subbasin (Hull 1984).

North American Subbasin

The general groundwater chemistry within the North American Subbasin can be characterized as magnesium-calcium bicarbonate in the shallower zones and sodium bicarbonate at depths up to about 850 feet. In the deepest parts of the aquifer system, the groundwater geochemistry is consistent with connate water in the marine sediments underlying the freshwater aquifers, suggesting a mix of connate and fresh water at depth. Elevated levels of TDS, chloride, sodium, bicarbonate, boron, fluoride, nitrate, iron, manganese, and arsenic may be of concern in some areas of the subbasin (DWR 1997).

Groundwater Quality Assessment by SRSC Service Area

DWR conducts water quality monitoring throughout the Sacramento Valley; however, the data collected are insufficient to provide a detailed characterization of the water quality within each contractor service area. For several service areas there are a limited number of groundwater quality monitoring wells – in some cases, only one well. Where possible, information from other investigations is included. Because of the lack of site-specific data, further characterization is needed.

The following summaries for each service area show the number of groundwater quality monitoring wells, monitoring well construction depth, available groundwater quality data and, where possible, the geochemical characterization of the local groundwater.

Table 44 summarizes the range of groundwater quality results obtained by DWR for each contractor service area. Plate 5 shows the location of the DWR groundwater quality monitoring wells.

Anderson-Cottonwood Irrigation District

DWR monitors groundwater quality in seven wells throughout the Anderson-Cottonwood Irrigation District. The wells are located within the Anderson and Enterprise subbasins. Six of the wells are listed as domestic use, and one is municipal. The domestic wells range in depth from 40 to 96 feet. The municipal well is constructed to a depth of 520 feet.

The groundwater can be characterized as a magnesium-calcium bicarbonate type with a hazard classification of C1-S1:

Table 44
Summary of analytical results by Settlement Contractor Service Area

	Anderson-Cottonwood Irrigation District	Glenn-Colusa Irrigation District	Princeton-Cordora-Glenn Irrigation District	Provident Irrigation District	Maxwell Irrigation District	Reclamation District 1004	Reclamation District 108	Natomas-Central Mutual Water Company	Pelger Mutual Water District	Sutter Mutual Water Company
PH	6.3 – 7.1	7.2 – 8.1	7.4	7.3	7.9	7.6	7.8	7.9 – 8.2	8.2	7.9 – 8.2
EC	128 – 391	315 – 2245	806	824	1854 – 2495	390	543	326 - 709	1070	718 – 1280
Calcium (mg/L)	8 – 29	33 – 93	63	55	128	26.2	31	24 - 44	35	28 – 35
Magnesium (mg/L)	6 – 23	18 – 67	49	57	92	22.2	23	9 - 27	34	17 – 34
Sodium (mg/L)	9 – 24	11 – 265	51	51	176	18.4	47	33 - 68	139	198
Potassium (mg/L)	0.8	< 0.5 – 2.0	1.4	< 0.5	2.6	0.360	3.3	- 2.9	—	—
Alkalinity (mg/L)	51 – 129	148 – 335	407	391	408	166	175	124 - 226	234	229 – 250
Sulfate (mg/L)	< 2 – 37	11 – 427	22	43	455	7.9	13	- 45	—	—
Chloride (mg/)	2 – 17	6 – 226	15	11	113	5.0	60	23 - 31	177	268 – 275
TDS (mg/L)	170 – 240	22 – 1320	475	473	1270 – 1430	245	323	- 619	—	—
Hardness (as CaCO3 mg/L)	44 – 167	157 – 508	359	372	699 – 836	134	172	97 - 221	223	140 – 228
Boron (mg/L)	< 0.5 – 0.7	< 0.1 – 0.5	0.2	0.2	0.4	0.1	0.4	- 0.3	—	—
Minor Elements										
Arsenic (mg/L)	< 0.0005 – 0.0006	< 0.001 – 0.002	0.003	0.002	0.003	0.0035	0.004	- 0.014	—	—
Barium (mg/L)	0.01 – 0.058	<0.05 – 0.218	0.257	0.320	0.055	0.106	0.072	—		
Cadmium (mg/L)	< 0.001	<0.001	< 0.005	< 0.005	< 0.005	< 0.001	< 0.005	—	—	—
Chromium (mg/L)	< 0.005	0.005 – 0.031	< 0.005	< 0.005	< 0.005	0.008	< 0.005 -	<0.005	—	—
Copper (mg/L)	< 0.005 – 0.17	0.003 – 0.03	0.007	0.008	0.007	< 0.003	< 0.005	—	—	—
Iron (mg/L)	< 0.005 – 0.09	< 0.02 – 0.792	0.015	0.014	0.055	0.027	0.017	- <0.1	—	
Lead (mg/L)	< 0.001 – 0.001	< 0.005 – 0.008	< 0.005	< 0.005	< 0.005	0.0021	< 0.005	—	—	
Manganese (mg/L)	< 0.005 – 0.006	< 0.001 – 0.116	< 0.005	0.082	0.034	< 0.001	< 0.005	- 0.272	—	
Selenium (mg/L)	0.001	< 0.0008 – 0.013	< 0.001	< 0.001	< 0.001	< 0.0008	< 0.001	- <0.001	—	
Zinc (mg/L)	0.138	0.01 – 0.24	0.082	0.011	0.112	0.104	0.019	—	—	

low salinity and low sodium. The overall groundwater quality of the DWR monitoring wells is considered good.

Glenn-Colusa Irrigation District

DWR monitors groundwater quality in 13 wells throughout the Glenn-Colusa Irrigation District. Eleven of the wells are for domestic use, one well is used for a combination of domestic/irrigation purposes, and one well is used as a combination domestic/stock well. The domestic wells range from 78 to 316 feet deep. The domestic/irrigation well is installed to a depth of 195 feet, and the domestic/stock well is 325 feet deep. The groundwater geochemistry is transitional with no single dominant cation-anion pair. The characterization includes sodium-magnesium bicarbonate, sodium-calcium bicarbonate, calcium-magnesium bicarbonate, and sodium bicarbonate water types and falls into a hazard classification of C2-S1 or C3-S1. The C2-S1 designation is for a medium salinity hazard and low sodium hazard. The C3-S1 designation is for a high salinity hazard and a low sodium hazard.

Monitoring data show high bicarbonate concentrations ranging from 148 to 335 mg/L in 12 of the 13 wells. The average concentration is 263 mg/L.

Two of the domestic wells had high concentrations of TDS and boron. State Well Number 15N/03W-01R01M, north of Williams, constructed to a depth of 316 feet, had a TDS concentration of 662 mg/L and a boron concentration of 0.5 mg/L. Domestic State Well Number 17N/02W-30J02M, west of Delevan National Wildlife Refuge, constructed to a depth of 182 feet, had a TDS concentration of 1,320 mg/L and a boron concentration of 0.5 mg/L.

In a 1992 investigation, three groundwater monitoring wells in the Sacramento National Wildlife Refuge were analyzed for hexavalent chromium to assess the hazards to area waterfowl if groundwater was used for habitat flood-up (Turner 1992). Two of the wells had hexavalent chromium concentration levels exceeding the acceptable limit of 11 μg/L for wildlife use. Concentration levels ranged from 18 to 22 μg/L and were noted at all depth zones in the sampled wells. Hexavalent chromium was also observed in several wells east of the refuge boundary at concentrations at or near the EPA standard of 11 μg/L.

In the early 1990s, increases in sodium and chloride concentrations were observed east of Maxwell (DWR 1990a). Test wells used in the investigation ranged in depth from 82 to 288 feet in the unconfined and semi-confined portions of the aquifer system. The area believed to be impacted extends from 2 to 3 miles east of Interstate 5 to about 2 to 3 miles west of the Sacramento River and from about 3 miles north of the Maxwell-Colusa Road to 2 miles south of Colusa. The area encompasses approximately 40 square miles.

Provident Irrigation District

DWR conducts groundwater quality monitoring for one well within the Provident Irrigation District. State Well Number 19N/02W-23N01M is a domestic well located near the center of the district drilled to a depth of 72 feet. Analytical results indicate that the general chemical character of the water is a transition type of magnesium-calcium bicarbonate, with a bicarbonate concentration of 391 mg/L. The water has a hazard classification of C2-S1, medium salinity and low sodium. Water quality of this well is considered good, with the exception of potentially high bicarbonate concentration.

Princeton-Codora-Glenn Irrigation District

Water quality monitoring is conducted for domestic State Well Number 18N/02W-01E01M, which was installed to a depth of 160 feet. The well is located in the central portion of the district. Monitoring results indicate that the general chemical character of the water is a transition type of magnesium-calcium bicarbonate with a bicarbonate concentration of 407 mg/L. The water has a hazard classification of C3-S1, high salinity and low sodium.

Maxwell Irrigation District

There are no wells within the Maxwell Irrigation District that are monitored for groundwater quality by DWR. However, DWR is monitoring domestic State Well Number 16N/02W-04H01M outside the northeast corner of MID. The well is installed to a depth of 190 feet.

Analytical results from two sampling events showed an average concentration for sodium and alkalinity at 165 and 371 mg/L, respectively. The concentration of TDS was measured at 1,270 and 1,430 mg/L. Based on these results, the general chemical character of the water is sodium sulfate with a hazard classification of C3-S2, a high salinity and medium sodium. The adjusted SAR from this well indicates the potential for root absorption and soil permeability problems if used for agricultural applications.

Domestic State Well Number 17N/02W-30J02M, located 2 miles to the northwest inside GCID, has comparable water quality. The average concentrations of sodium and alkalinity are 261 and 305 mg/L, respectively. The average TDS concentration is 1,270 mg/L.

The data from these wells indicate that groundwater quality is generally poor for the northern portion of MID. There are insufficient data to determine the general groundwater quality in the remaining areas of the district.

Reclamation District 108

DWR conducts groundwater quality monitoring for two domestic wells and one irrigation well. The domestic wells near the center of Reclamation District 108 are installed to depths of 180 and 364 feet. The irrigation well is north of the district at a depth of 310 feet.

The groundwater geochemistry is a transition type of sodium-magnesium and calcium-magnesium bicarbonate and has a hazard classification of C2-S1, medium salinity and low sodium. The adjusted SAR for these wells indicates a potential for root absorption and soil permeability problems.

In 1997, DWR analyzed laboratory data from 129 wells as part of a pre-feasibility investigation for a potential conjunctive use project in the lower Colusa Basin (DWR 1997a). The project area included the eastern third of Yolo County and part of Solano County. Results of the evaluation identified the potential for elevated concentrations of TDS and boron. TDS concentrations ranging from 500 to 1000 mg/L were observed south of Woodland, and in the general region of Davis and along the eastern extents of Putah Creek. Boron levels ranging from 0.75 to greater than 2 mg/L were observed throughout the study area. The highest concentrations were found south of Woodland and at the Yolo Bypass near Interstate 5 (DWR 1997a).

Where the TDS and boron concentrations have been a concern, water has been diluted for irrigation purposes with other sources of groundwater or surface water.

Reclamation District 1004

There are no wells within RD 1004 being monitored by DWR for groundwater quality. However, DWR is monitoring State Well Number 17N/01W-06R01M, an irrigation well located outside the northwestern portion of the district. The well is completed to a depth of 271 feet. The chemical character of the water is a transition type of calcium-sodium bicarbonate and classified as C2-S1, a medium salinity hazard and a low sodium hazard.

Another well east of RD 1004, monitored as part of a previous DWR groundwater investigation, is State Well Number 17N/01E-17F. This well is a multi-completion well monitoring shallow, medium, and deep water-bearing zones. The zones range from 130 to 150 feet, 312 to 332 feet, and 505 to 535 feet, respectively. The chemical character of the water changes with depth from a sodium-magnesium bicarbonate to a sodium bicarbonate. The concentrations of chloride and total dissolved solids increase with depth from 4 to 170 mg/L and 180 mg/L to 500 mg/L, respectively. The sodium hazard is low; however, the salinity hazard increases with depth and is classified as high in the deepest zone (DWR 1992a).

Sutter Mutual Water Company

DWR conducts groundwater quality monitoring for State Well Number 12N/02E-02Q01M and State Well Number 13N/02E-17A01M, within the southern half of Sutter Mutual Water Company. The wells are 204 and 149 feet deep, respectively. The general chemical character of the water is sodium-magnesium bicarbonate and has a hazard classification of C3-S1, high salinity and low sodium.

Between 1964 and 1967, DWR conducted a groundwater quality investigation. The study area included portions of the SMWC service area. Analyses from the investigation showed TDS concentrations ranging from 205 to 5,610 mg/L, with an average of 1,549 mg/L. Boron concentrations ranged between 0.1 and 1.1 mg/L.

In a study conducted by the University of California at Davis, drainage water was evaluated for electrical conductivity and chloride concentration to assess the occurrence and movement of salt and groundwater within the district. The investigation focused on shallow groundwater, typically within the upper 10 feet of the surface.

The investigation identified higher electrical conductivity and chloride concentrations in drain samples from areas south of the Sutter Basin Fault and within the region between the main drainage canal and the Sutter Bypass. In the areas north of the fault and west of the main drain, electrical conductivity and chloride concentrations were low. Similar results were observed adjacent to the Sutter Bypass.

Saline groundwater contributes substantially to the composition of drain water even during months when groundwater constitutes a small portion of the total volume. In addition, upward seepage of groundwater is occurring within the SMWC area by as much as 17 inches per year, or 100,000 acre-feet. Although upwelling of high saline groundwater is occurring regularly, soil salinity levels in the SMWC area were found to be generally low, likely because of the flushing of water percolation from flood irrigation of rice fields (Henderson and others 1972). The overall groundwater quality within the SMWC service area is considered poor.

Pelger Mutual Water District

No wells in Pelger Mutual Water District are being monitored by DWR for groundwater quality. The nearest DWR monitoring well, State Well Number 13N/02E-23B01M, is 1 mile east of the district. Groundwater quality was monitored in this well between 1964 and 1967. Similar to wells within SMWC, the water quality of this well is considered poor, with a TDS concentration of 5,970 mg/L and boron concentration of 0.4 mg/L.

In 1992, DWR conducted a water quality analysis for State Well

Number 13N/02E-19D01M, located north of PMWD (DWR 1992). The TDS concentration of groundwater was 685 mg/L, and the boron concentration was 0.3 mg/L. The SAR and adjusted SAR were 4.1 and 8.7, respectively. Based on this data, the groundwater geochemistry is characterized as sodium bicarbonate and has a hazard classification of C3-S1, high salinity and low sodium.

Natomas Central Mutual Water Company

DWR assessed groundwater quality in the Natomas Central Mutual Water Company as part of a conjunctive use investigation (DWR 1997). Water quality data were compiled from approximately 150 wells monitored by DWR, USGS, the Department of Health Services, and the Department of Pesticide Regulation. General constituents were analyzed for physical parameters, ionic parameters, trace elements, and agri-chemicals. The chemical character of the water is sodium-magnesium and calcium-magnesium bicarbonate.

Water quality in the NCMWC area includes groundwater with high concentrations of chloride and sodium, and TDS levels exceeding 450 mg/L may be found west of Highway 99 between the Cross Canal to the north and I-5 to the south. Concentrations of boron may exceed 0.5 mg/L in the region bounded by the Sutter-Sacramento county line, the Sacramento River, and I-5. Groundwater with high concentrations of bicarbonate extends from south of I-5 to the water company's northern boundary. Concentrations of manganese may exceed 0.2 mg/L from the Natomas Cross Canal south to I-5 and west of U.S. Highway 99 to the Sacramento River.

Land Subsidence

Land Subsidence

Land subsidence is the compaction of soil or earth materials that occurs in shallow to deep zones. Subsidence has little effect on land use or the overall landscape but has the potential to cause flood control problems if allowed to occur undetected and unmitigated. Subsidence reduces the freeboard of levees, allowing water to breach them more easily. It can change the grade, or even the direction of flow, in canals. Subsidence can also damage wells by collapsing well casings.

Mechanics of Land Subsidence

Land subsidence is controlled by the interaction of many factors. As hydrostatic heads decline in response to groundwater withdrawals, clay beds between production zones are exposed to increased vertical loads. These loads can cause clay beds to consolidate, which, in turn, leads to land subsidence. Other factors that influence the rate and magnitude of consolidation in clay beds include mineral composition, sorting, the amount of prior consolidation and cementation, the degree of aquifer confinement, porosity, permeability, and bed thickness. The confined Tertiary-Quaternary clay sediments are the most susceptible to subsidence.

Consolidation has elastic and inelastic components. As the head in the aquifer system is lowered, the overburden load that was supported by hydrostatic pressure is transferred to the granular skeletal framework of the formation. As long as the increased formation load does not exceed either the pre-consolidation pressure or the maximum load the formation has experienced since its deposition, the consolidation of the formation will remain elastic. Under conditions of elastic subsidence, the formation will rebound to its original volume as the hydrostatic pressure is restored. However, when the hydrostatic head of the formation is lowered to a point where the overburden load exceeds the pre-consolidation pressure, inelastic consolidation occurs. Under inelastic subsidence, the formation will undergo a permanent volumetric reduction as water is expelled from the clays. Although there are theoretical methods to estimate the potential for consolidation, practical implementation of the theories is limited by the lack of detailed data and the simplified assumptions of the theories. Existing data indicate that significant local subsidence is not expected to occur as long as groundwater levels remain above the historical lows for the region.

Previous Land Subsidence Investigations in the Sacramento Valley

Little attention has been given to the potential for land subsidence in the Sacramento Valley until recently. In the early 1970s, USGS, in cooperation with DWR, preformed a preliminary investigation to identify areas of possible land subsidence in the Sacramento Valley. These studies looked at changes in Sacramento Valley elevations along survey lines containing first and second order benchmarks. Findings from the work indicate that some local subsidence occurred between 1934 and 1942, and again between 1964 and 1967. Historic subsidence was measured at less than 1 foot between Zamora and Davis, and as much as 2 feet in the area east of Zamora and west of Arbuckle. The findings also indicate that subsidence extends north to near Willows, at a magnitude of less than 6 inches.

In 1987, DWR and USGS installed an extensometer in the Zamora area to monitor real-time land subsidence. Data from the device confirmed that active land subsidence was occurring as a result of groundwater extraction in the Zamora area, and that drought conditions enhance the rate and magnitude of the land subsidence.

In 1994, USGS used Global Positioning System surveying to investigate land subsidence rates in the lower Sacramento Valley. The investigation focused on changes in elevation for 21 benchmarks in the southern Sacramento Valley between 1986 and 1989. The study concluded that subsidence occurred at rates of up to 4 cm/yr, for areas centering on Davis and extending southwesterly toward Dixon, and in the area centered on Woodland and extending northwesterly toward Zamora. Findings also revealed that rates of subsidence greater than 1 cm/y had occurred in a northwest-trending zone extending from Zamora toward Arbuckle.

Between 1991 and 1999, DWR installed four more extensometers in the Sacramento Valley. The installation dates and locations of the

four devices are listed below:
1. 1991 - Yolo County, west of Woodland
2. 1993 - Sutter County, south of Nicolas
3. 1999 - Butte County, west of Chico
4. 1999 - Butte County, west of Nelson

Records from Yolo and Sutter county extensometers show that subsidence is not a problem in these areas. The two extensometers recently installed in Butte County do not yet have enough data to perform a meaningful analysis.

Yolo County recently began developing a countywide global positioning system surveying network for monitoring future land subsidence. The City of Davis was selected to be the administrator for the project. This project was undertaken with the following federal, state, and local agencies:
City of Davis
City of Woodland
University of California, Davis
California Department of Water Resources
U.S. Army Corps of Engineers, Topographic Engineering Center
U.S. Bureau of Reclamation
California Department of Transportation (Caltrans)
Yolo County Department of Public Works
Yolo County Flood Control and Water Conservation Agency

The program established a network of GPS benchmarks throughout Yolo County, and determined an initial GPS elevation for each benchmark. The initial observations will be compared to future sets of observations to identify areas and determine magnitudes of subsidence that occurred between the observations periods. The initial GPS observations were started July 2, 1999. At the present time, the second round of observations have not been scheduled.

Land Subsidence Potential

Subsidence is most prone to occur, and will occur most rapidly, in areas where the following geologic and hydrologic conditions exist:

Strongly confined aquifer system

- Coarse-grained aquifers with multiple thin clay interbeds
- Clay interbeds subject to low natural pre-consolidation pressures
- Large potentiometric head declines from groundwater extraction

A matrix, shown in Table 45, was developed to estimate the potential for future land subsidence under existing hydrologic conditions. It attempts to quantify the four factors identified above for each district. Much of the data used to develop the matrix is somewhat subjective and should be used with caution. The matrix does not evaluate the subsidence potential if future hydrology in any of the regions changes significantly.

The degree of aquifer confinement was estimated by examining groundwater level data for monitoring wells in each district. This analysis was combined with our general understanding of the aquifer system to assign a degree of confinement rating that ranged from low to high. The thickness of clay bed intervals was evaluated by examining all electric logs on file for each district. The short normal resistivity portion of the electric log was used to identify clay interbeds, then to assign a qualitative rating that ranges from thin to thick. The degree of pre-consolidation was the most subjective and difficult to estimate. In this analysis, it was assumed that wells drawing from Pleistocene age or older formations were drawing from sediments that have undergone some degree of pre-consolidation. Finally, the head change was evaluated by examining historical groundwater levels in each district.

The overall subsidence potential was assigned by examining all the factors that contribute to land subsidence for each district. The overall subsidence potential for all districts is low, with the exception of those districts in the south-central portion of the Colusa Subbasin. This is an area that has experienced some historical subsidence and will probably experience some degree of subsidence in the future. This area was assigned a low to moderate potential for future subsidence. Districts in the West Sutter Subbasin were assigned a low subsidence potential primarily because of the general lack of groundwater use. This may be an area where subsidence could be a problem if additional groundwater development occurs. If it becomes necessary to increase groundwater development in any district, it would be prudent to implement a corresponding subsidence-monitoring program. This is especially true in districts that have been identified as having a medium to high degree of aquifer confinement (see Table 45).

Table 45
Matrix of subsidence potential

	Aquifer Confinement	Clay Interbed Thickness	Preconsolidation	Head Changes	Overall Subsidence Potential
Anderson-Cottonwood Irrigation District	Low – Medium	Medium – Thick	Medium – High	Low	Low
Glenn-Colusa Irrigation District:					
Stoney Creek Fan Area	Low – Medium	Medium – Thick	Medium – High	Low	Low
Central Colusa Basin	Medium – High	Medium – Thick	Medium	Low	Low – Medium
Provident Irrigation District	Low – Medium	Medium – Thick	Medium	Low	Low
Princeton-Codora-Glenn Irrigation District	Low – Medium	Medium – Thick	Medium	Low	Low
Maxwell Irrigation District	Medium – High	Medium – Thick	Medium	Low	Low – Medium
Reclamation District 1004	Medium – High	Thick	Low – Medium	Medium	Low
Reclamation District 108	Medium – High	Thick	Medium	Low – Medium	Low
Pelger Mutual Water Company	Medium – High	Thick	Uncertain	Low	Low
Sutter Mutual Water Company	Medium – High	Thick	Uncertain	Low	Low
Natomas Central Mutual Water Company	Low – Medium	Medium – Thick	Medium	Medium	Low

* Aquifer confinement is defined as the degree of confinement within the primary producing zone of the aquifer system. The main producing zone is defined as the interval plus or minus one standard deviation around the mean well depth.

Groundwater Management Plans and County Ordinances

Groundwater Management Plans and County Ordinances

Water transfers that occurred during the drought of the early 1990s led to the enactment of county ordinances and local groundwater management plans to protect and preserve the groundwater resources of the Sacramento Valley. This chapter summarizes these ordinances and groundwater management plans within the Sacramento Valley. These local regulatory guidelines will help guide future groundwater development and the implementation of conjunctive management of water resources in the valley.

Groundwater Management Plans

On Jan. 1, 1993, Assembly Bill 3030 - the Groundwater Management Act - became law and was written into the California Water Code as Section 10750 et seq.

The legislation was designed to provide local water purveyors with a tool to develop and implement groundwater management plans. The Groundwater Management Act encourages local water agencies to adopt groundwater management plans and programs to ensure efficient use, safe production, and quality of local groundwater resources. AB 3030 provides 12 elements as guidelines for local Groundwater Management Plans. The 12 elements are:

1. the control of saline water intrusion,
2. identification and management of wellhead protection and recharge areas,
3. regulation of the migration of contaminated groundwater,
4. the administration of a well abandonment and well destruction program,
5. mitigation of conditions of overdraft,
6. replenishment of groundwater extracted by producers,
7. monitoring of groundwater levels and storage,
8. facilitating conjunctive use operations,
9. identification of well construction policies,
10. the construction and operation by the local agency of groundwater contamination cleanup, recharge, storage, conservation, water recycling, and extraction projects,
11. the development of relationships with state and federal regulatory agencies, and
12. the review of land use plans and coordination with land use

planning agencies to assess activities which create a reasonable risk of groundwater contamination.

AB 3030 also allows coordination of regional groundwater management through the formation of joint powers agreements between individual water service agencies, or memoranda of understanding between water service agencies and other public or private entities.

Several coordinated basinwide groundwater management plans have been developed in the northern Sacramento Valley. Groups participating in basinwide management plans include the Redding Area Water Council and the Tehama County Flood Control and Water Conservation District. To the south, in northern Sacramento, southeastern Sutter, and western Placer counties, coordinated groundwater management has been pursued by the Sacramento Metropolitan Water Authority, the Sacramento Area Water Forum, the Sacramento North Area Groundwater Management Authority, and the Placer County Water Agency. Groundwater management plans relevant to the Sacramento River Settlement Contractors' Basinwide Water Management Plan are summarized below by basin and subbasin areas.

Redding Groundwater Basin

Most of the Redding Groundwater Basin falls within Shasta County. An association of public and private groundwater users called the Redding Area Water Council is implementing a cooperative AB 3030 Groundwater Management Plan, with the Shasta County Flood Control and Water Conservation District serving as the lead agency. Goals of the plan include monitoring and protecting the quality of groundwater in the basin while educating the public and establishing stronger community relations. The Council's approach to groundwater management is based upon voluntary cooperation among water agencies, purveyors, and interested private parties, with emphasis on information gathering and monitoring. The Council will also assess the need for short- and long-term facilities and evaluate options for conjunctive use of the basin's surface water and groundwater supplies. A report on the status of the Redding Groundwater Basin will be prepared using existing data from the federal, state, and local agencies' monitoring programs where possible.

Through cooperation with agencies such as the County Division of Environmental Health, the Water Council will support water quality monitoring, wellhead protection, and the proper construction and abandonment of wells. Working relationships with all water purveyors in and around the basin will be developed to address potential impacts related to land use and water supply decisions.

The following are members of the Redding Area Water Council:
City of Anderson
City of Redding
City of Shasta Lake
Shasta County Water Agency
Anderson-Cottonwood Irrigation District
Bella Vista Water District
Clear Creek Community Services District
Centerville Community Services District
Cottonwood Water District
Shasta Community Services District
Mountain Gate Community Services District
Simpson Paper Company
The McConnell Foundation

A small part of the southern Redding Groundwater Basin falls within Tehama County. The Tehama County Flood Control and Water Conservation District is working as the lead agency to implement a coordinated AB 3030 plan for the Tehama County area. This plan addresses the management of groundwater resources in the Bend, Antelope, Dye Creek, Los Molinos, Vina, Corning, and Red Bluff subbasins, as well as the southern part of the basin. The plan is designed to be responsive to individual private pumpers who constitute the majority of groundwater users in the county. These private pumpers will be brought into the plan through coordination with rural and civic organizations such as the Farm Bureau, resource conservation districts, watershed conservancies, chambers of commerce, and others. Several management level options (passive, limited, and active) are included in this plan. "Trigger levels" established for each subbasin will determine the appropriate management level. Initial emphasis will be placed on groundwater monitoring and basin evaluation efforts. Data collection efforts by DWR, USBR, and USGS will be determined and any data gaps will be identified. All 12 of the AB 3030 plan elements will be addressed if conditions warrant and if sufficient community support for the management options has been expressed. Whenever possible, groundwater management activities will be limited to those which are least intrusive to local landowners.

Sacramento Valley Groundwater Basin

Colusa Subbasin

The Colusa Subbasin covers portions of Glenn, Colusa, and Yolo counties. Within the Colusa Subbasin, individual and cooperative AB 3030 plans have been adopted. Glenn-Colusa Irrigation District and Reclamation District 108 have adopted individual plans. Princeton-Codora-Glenn (PCGID) and Provident Irrigation districts (PID) have entered into a joint AB 3030 plan.

Glenn-Colusa Irrigation District (GCID) addresses seven of the 12 plan elements in its AB 3030 Plan. Elements not included may be adopted later if deemed necessary by the district's Board of Directors. The plan's primary component is the monitoring of groundwater levels and storage. Studies will be conducted to determine the subbasin's hydraulic properties including permeability, infiltration rates, specific yield and transmissivity, and the subbasin's vertical and horizontal extent. GCID's AB 3030 Plan includes continuation of its support for the replenishment of groundwater extracted by producers and for conjunctive use of groundwater and surface water supplies. GCID recognizes that future studies may reveal the need for the investigation, construction, and operation of groundwater recharge facilities.

Several elements related to water quality are addressed in this AB 3030 plan. GCID will cooperate with agencies having jurisdiction over well construction, abandonment, and destruction programs, and will provide information on proper well construction and destruction to well owners. GCID will work with local planning agencies to coordinate land use decisions and potential water supply options. They will also coordinate with state and federal regulatory agencies to ensure conformity with approved management practices and to avoid duplication of efforts.

RD 108, located in the southeastern portion of the Colusa Basin, has also adopted an AB 3030 plan. This plan focuses on collecting existing water level, water quality, and geologic data. Data collected will be used to determine the basin size and quantify the basin's safe yield. RD 108 will also develop recommendations on conjunctive use and on limitations of the commingling of surface water and groundwater supplies. The development of relationships with state, federal, and local agencies is also a component of this plan.

A third AB 3030 plan within the Colusa Subbasin has been adopted by the PCGID and PID, located west of the Sacramento River in the northern part of the Colusa Subbasin. This plan's objectives are to "increase the understanding of the districts' underlying groundwater basin" and to "coordinate the acquisition, compilation, and evaluation of groundwater data and management of the groundwater basin with districts or agencies having jurisdiction over adjacent lands." Of the 12 AB 3030 Plan elements, highest priority was given to monitoring groundwater levels and storage, the facilitation of conjunctive use operations, and the development of relationships with federal and state agencies. Only three AB 3030 Plan elements were selected for the Initial Phase Program to ensure the successful implementation of these priority elements under limited financial resources. AB 3030 Plan elements which were not identified as high priority will not be addressed in the Initial Phase Program, but may be implemented over time.

In the southern part of the Colusa Subbasin, the Yolo County Flood Control and Water Conservation District (YCFC&WCD) is developing a water management plan addressing the conjunctive use of surface water and groundwater supplies. Because the YCFC&WCD service area extends south from the Colusa Subbasin into the Yolo Subbasin, groundwater management in both subbasins will be addressed.

West Butte Subbasin

In the West Butte Subbasin, along the east side of the Sacramento

River, Western Canal Water District (WCWD) has adopted an AB 3030 plan. The WCWD service area extends from the West Butte Subbasin into the East Butte Subbasin, including areas of Glenn and Butte counties. WCWD will monitor groundwater levels and water quality to determine baseline levels and changes that might occur due to saline water intrusion or the movement of contaminants into the aquifer. WCWD has cooperated on the development of the Butte Basin Groundwater Model. In cooperation with the Butte Basin Water Users Association, WCWD will continue to update and monitor this model to assess the impacts of groundwater extractions and management practices within the Butte Basin. WCWD will also encourage the development of data about how groundwater within WCWD is replenished. WCWD will maintain an active program for the protection and use of its surface water rights to ensure the availability of a water supply for groundwater replenishment. The district will facilitate the conjunctive use of surface water supplies from State Water Project facilities at Thermalito Afterbay and groundwater supplies produced through privately-owned deep wells. Also included is the development of relationships with state and federal regulatory agencies, DWR, Glenn and Colusa counties, the Association of California Water Agencies, the Northern California Water Association, and neighboring water districts.

In the southern part of the West Butte Subbasin, Reclamation District 1004 is developing an AB 3030 plan. RD 1004 is located primarily in Colusa County; however, small portions extend into southern Glenn County and into western Sutter County in the East Butte Subbasin.

West Sutter Subbasin

In the West Sutter Subbasin, between the Sutter Bypass and the Sacramento River, Reclamation District 1500 (RD 1500) has adopted an AB 3030 plan. The boundaries of RD 1500 roughly coincide with the boundary of Sutter Mutual Water Company and include the Pelger Mutual Water Company. The plan's purpose is to coordinate data collection to develop and implement a plan that manages and monitors groundwater resources. RD 1500 will monitor static and pumping water levels and water quality. Conjunctive use concepts have been applied within RD 1500 through drain water recycling, but water quality monitoring has shown that shallow, saline groundwater seeps into drainage canals in some parts of RD 1500, diminishing irrigation water quality. Plans to enhance conjunctive use will not be developed until sufficient water quality data have been collected to define the limitations on commingling of groundwater and surface water supplies.

North American Subbasin

The North American Subbasin includes portions of Sacramento, Placer, and Sutter counties. In the Sacramento County portion of this subbasin, several cooperative groundwater management efforts have been developed. In 1994, the Sacramento Metropolitan Water Authority adopted an AB 3030 plan in conjunction with managers of water service agencies in Sacramento County. Placer and El Dorado counties and the City of Roseville were invited to participate in this Initial Phase Plan.

Elements given emphasis in this AB 3030 Plan include:

- formulation and implementation of a wellhead protection program,
- coordinated management of the cleanup and mitigation of contaminated groundwater,
- implementation of a plan combining conjunctive use,
- reduction of aquifer demands and improvement of recharge capabilities, and
- review of land use plans by interested water entities.

In December 1998, Reclamation District 1000 and Natomas Mutual Water Company adopted a "Resolution of Intention to Draft an AB 3030 Plan" and are working on its development. The Natomas Mutual Water Company also participates in the Sacramento North Area Groundwater Management Authority (SNAGMA). A joint powers agreement provides legal authority for SNAGMA to manage groundwater in the area of Sacramento County that lies north of the American River. Other participants in SNAGMA include:

Arcade Water District
Carmichael Water District
Citizens Utilities

Citrus Heights Irrigation District
City of Folsom
City of Sacramento
County of Sacramento
Del Paso Manor Water District
Fair Oaks Water District
Northridge Water District
Orangevale Water District
Rio Linda/Elverta Community Water District
San Juan Suburban Water District
Southern California Water District

Natomas Central Mutual Water Company is pursuing cooperative groundwater management through participation in the Sacramento Area Water Forum (SAWF). Participants include representatives from business, environmental, and civic interests and water suppliers from the Sacramento and foothill areas. The focus of the SAWF groundwater management efforts includes all of Sacramento County except the southernmost area.

In the Placer County portion of the North American Subbasin, groundwater management is under the authority of the Placer County Water Agency, which has adopted an AB 3030 plan for western Placer County. The County of Placer, the City of Roseville, and the City of Rocklin are partners in the plan's preparation. The plan has the support of Citizens Utilities, San Juan Suburban Water District, South Sutter Water District, and the Sacramento Metropolitan Water Authority. The plan's main objective is "to facilitate studies and actions needed to restore and maintain the quantity and quality of the groundwater in the basin." AB 3030 Plan elements include monitoring groundwater levels and water quality, identifying opportunities for groundwater recharge and conjunctive use, and evaluating safe yield. The plan also includes coordination with all jurisdictions, landowners, and the general public within western Placer County, with jurisdictions in northern Sacramento County, and with state and federal agencies. Although a preliminary study of this plan documented a significant decline (1.5 ft/yr) in groundwater levels, implementation of projects to alleviate this decline will be conducted separately.

Extending from Sutter into Placer county in the North American Subbasin, the South Sutter Water District has adopted an AB 3030 plan to manage groundwater. This plan includes groundwater level and water quality monitoring, and continuing and possibly expanding conjunctive use operations at the Camp Far West Project. The plan also includes working cooperatively with DWR, the Sutter County Agricultural Commissioner, and other state and federal regulatory agencies.

County Groundwater Ordinances

County ordinances or local acts authorized under California State Law provide for local management of groundwater resources. Within the Sacramento Valley, counties that have adopted groundwater ordinances, or are working under a State-authorized act, include Shasta, Tehama, Glenn, Butte, Colusa, Yolo, and Sacramento. All but the Glenn County ordinance establishes a permit application and approval process before exporting groundwater outside the county or operating a groundwater/surface water substitution program. An environmental review of the proposed program is required as part of the permit process. The cost of the permitting process is the responsibility of the applicant. Issues of concern, addressed in the local ordinances, include groundwater overdraft, land subsidence, saltwater intrusion, third party impacts, and impact to long-term groundwater storage or aquifer productivity. In addition to the groundwater export ordinances, Butte, Colusa, and Glenn counties have adopted groundwater ordinances that address well spacing along with health and safety issues.

Groundwater management in the Sacramento area is being pursued under the Sacramento County Water Agency Act, Sections 32 through 33. Pursuant to this Act, State law authorizes the Sacramento County Water Agency to manage surface and groundwater resources within groundwater management zones established by the agency.

The following section summarizes by county the ordinances and acts used to manage groundwater resources in the Sacramento Valley.

Shasta County

On Jan. 27, 1998, Shasta County adopted "Shasta County Ordinance No. SCC 98-1, an Ordinance of the County of Shasta Repealing Ordinance No. SCC 97-6 and Adopting Chapter 18.08 'Groundwater Management' Regarding the Extraction and Exportation of Groundwater from Shasta County." This ordinance requires a permit for extraction of groundwater underlying lands in Shasta County, either directly or indirectly. Groundwater extraction under this ordinance includes groundwater used to replace surface water supply that has been, is being, or will be, exported for commercial purposes. It does not apply to the extraction of groundwater for the following purposes:

To prevent the flood of lands

To prevent the saturation of the root zone of agricultural land

For use within the boundaries of a local agency which is located in part within Shasta County and in part in another county where the extraction quantities and use are consistent with historical practice

For extractions to boost heads for portions of local agency facilities, consistent with the historical practice of the local agency

To enable export that is expressly permitted by terms of an adopted groundwater management plan

Where the person or entity demonstrates to the satisfaction of the Chief Engineer of the Shasta County Water Agency that its water management practices will result in an average annual groundwater basin recharge which is equal to or in excess of its extraction of groundwater for export

Applications are filed with the Shasta County Water Agency on a form specified by its Chief Engineer. In addition to requesting information on this form, the Chief Engineer may request additional information to address specific aspects of the proposed groundwater export. The applicant must consent to the commencement and funding of an environmental review as required by the California Environmental Quality Act and local guidelines.

Within 10 calendar days of the filing of the permit application and payment of applicable fees, the Chief Engineer will post a notice of the filing on the Public Works Department bulletin board. A copy of the notice will be sent to all local agencies within Shasta County with jurisdiction over lands adjacent to, or overlying, the location of the proposed extraction. Notices will also be sent to any interested party who has made a written request to the Chief Engineer for such notice within the past 12 months. The Chief Engineer will determine whether the application is complete and commence an appropriate environmental review in accordance with CEQA.

The Chief Engineer will review the application with County staff, DWR, the Regional Water Quality Control Board, and local agencies. Any person or agency may provide written comments within 30 days of the posting and mailing of the notice. Permits are approved or denied by an appointed Commission, a nine-person decision-making body representing Shasta County, the cities of Redding, Anderson, and Shasta Lake, independent water districts, agricultural water users, and industrial water users. Upon completion of the environmental review, the application, and written comments, the environmental review and the Chief Engineer's recommendations are forwarded to the Commission for public review.

The Commission considers all potential impacts of the proposed export on the aquifer, including those affecting the potential hydraulic gradient, hydrology, percolation, permeability, piezometric surface, porosity, recharge, annual yield, specific capacity, spreading waters, transmissivity, usable storage capacity, water table, and zone of saturation.

A permit may be granted if a majority of commissioners is present at the public meeting, and the majority determines that the proposed groundwater extraction will not have significant detrimental impacts. The Commission must determine that the proposed extractions:

- will not cause or increase an overdraft of the groundwater underlying the County,
- will not affect the long term ability for storage or transmission of groundwater within the aquifer,

will not exceed the annual yield of groundwater underlying the County and will not otherwise operate to injury of the reason able and beneficial uses of overlying groundwater users,

will not result in an injury to a water replenishment, storage, or restoration project operating in accordance with statutory authorization,

is in compliance with Water Code Section 1220, and

will not be otherwise detrimental to the health, safety, and welfare of property owners overlying or in the vicinity of the proposed extraction sites.

If the Commission finds that the applicant will provide adequate mitigation to offset all adverse impacts, the permit may be granted. Permit issuance is subject to conditions imposed by the Commission to prevent groundwater overdraft or other adverse conditions.

If a permit has been denied by the Commission, a reapplication may not be filed until the following water year (October 1 through September 30). The reapplication will be considered only if it demonstrates a significant change in the circumstances that formed the basis of the previous permit application denial. A permit denial by the Commission may be appealed by filing a written request with the Clerk of the Shasta County Board of Supervisors within 15 days of the issuance of the decision. The appeal must specify the procedural and substantive reasons for the appeal.

During the term of the permit, the extraction of groundwater may be challenged based upon the following circumstances:

There has been or is an ongoing violation of one or more conditions of the approved permit;

The extraction of groundwater has caused or increased overdraft in the basin; has adversely affected the long term ability for storage or transmission of groundwater in the affected aquifer; exceeds the annual yield of the affected groundwater basin; operates to the injury of the reasonable and beneficial uses of overlying groundwater users; is in violation of Water Code 1220; or results in injury to a water replenishment, storage, or restoration project operating in accordance with statutory authorization; or

The continued extraction of groundwater pursuant to the permit will be detrimental to the health, safety and welfare of one or more affected local agencies or other interested parties.

Approved permits are valid for a term determined by the approving body, but cannot exceed 3 years. If less than four months remain in the current water year at the time a permit is granted, then the current water year will not be included in the 3-year term. However, if the extraction is part of a conjunctive use program, the term of the permit may not exceed the length of the term of that program.

Glenn County

Glenn County has adopted a groundwater Management Ordinance. The "Ordinance Amending the County Code, Adding Chapter 20.03, Groundwater Management" was passed by the Glenn County Board of Supervisors in February 2000. This ordinance takes a different approach to protecting the local groundwater resource than those in other parts of the Sacramento Valley. Many of the other ordinances generally have a comprehensive permitting and review process for water transfers and do little to effectively manage the resource. The Glenn County Ordinance, however, depends on a countywide monitoring program, sound scientific evaluation of monitoring data, and good groundwater management practices to protect the resource.

The ordinance divides the county into a number of hydrologically similar sub-areas. In each sub-area, acceptable changes in groundwater levels, groundwater quality, and amounts of inelastic land subsidence are defined. The local water users define these Basin Management Objectives, or BMOs, for their area. The sub-areas are combined into a countywide BMO that is approved annually by the Board of Supervisors. Results from the monitoring program are used to ensure compliance with the BMO components. The ordinance establishes a Water Advisory Committee and Technical Advisory Committee to review the monitoring data and to make recommendations to the Board of Supervisors, which acts as the enforcement agency for the ordinance.

As long as the BMO criteria are maintained, the county takes no action and monitoring of the resource continues. If one, or more, of the BMO criteria is exceeded, the ordinance requires public reporting of the situation and sets into motion a fact-finding process to determine the cause or causes for the BMO noncompliance. The

Technical Advisory Committee reviews all pertinent information and makes recommendations to resolve the BMO noncompliance to the Water Advisory Committee. The Advisory Committee reviews the options and makes its own recommendation for action to the Board of Supervisors.

Tehama County

Ordinance No. 1617 - "An Ordinance Repealing, Enacting and Reenacting the Substantive Provisions of Ordinances 1552 and 1553 of the County of Tehama," adopted Jan. 18, 1994 - requires a permit for the transfer of extracted groundwater. Permits are required for transfers within Tehama County and for transfers to other counties. This ordinance restricts the radius of influence (cone of depression) of wells first put into operation after 1991. Some exceptions are made for domestic and water system wells.

Applications for permits are filed with the Tehama County Health Agency, Environmental Health Division. A request for environmental review must be filed concurrently. Permits are reviewed by the Health Agency, the Agricultural Commissioner, the Planning Director, DWR, and the RWQCB.

The County Technical Advisory Committee reviews the permit application after all comments have been received and a final report is submitted to the Board of Supervisors. The Board holds a public hearing and determines whether to issue the permit.

A permit may only be granted where the Board finds that the extraction and transfer will not:

bring about an overdraft,

bring about salt water intrusion,

adversely affect transmissivity within the aquifer,

adversely affect the water table, or

result in the mining of water.

The Board may issue a permit if it finds that the applicant has provided for mitigation to offset any adverse effect.

Colusa County

"Colusa County Ordinance No. 615 - an ordinance of the Board of Supervisors of the County of Colusa adding Chapter 43 to the Colusa County Code prohibiting the extraction and exportation of groundwater from the County of Colusa," adopted Aug. 25, 1998 - requires a permit for pumping groundwater underlying Colusa County, directly or indirectly, for use outside of the county. The extraction of groundwater to replace a surface water supply transferred for use outside of Colusa County is subject to this ordinance. A request for environmental review and payment of fees established by the Colusa County Board of Supervisors must accompany the permit application.

Permits are not required for the extraction of groundwater under the following circumstances:

- To prevent the flood of lands
- To prevent the saturation of the root zone of agricultural lands
- For use within a local agency which is located in part in Colusa County and in part in another county, where extraction quantities and use are consistent with historical practices, and the local agency has adopted a groundwater management plan consistent with the Colusa County Groundwater Management Plan,
- For use on lands outside of Colusa County which are contiguous to and in the same ownership as lands within the county from which the groundwater is extracted where rates, quantities, and use are consistent with the landowner's historical practices. Water export that is expressly permitted by the terms of the Colusa County Groundwater Management Plan is also excluded.

The Commission may grant a revocable exemption to water districts that have properly filed an application and complied with all of the following:

- Adopted a groundwater management plan pursuant to Water Code Section 10750 et seq. that has been approved by the Colusa County Groundwater Commission
- Instituted a groundwater monitoring and mitigation program which has been approved by the Commission
- Executed an Agreement with the County of Colusa which requires the parties to share groundwater monitoring information and data, coordinate their efforts to monitor groundwater

resources, and participate in the development and preparation of a groundwater management plan by the County

The permit application, consent for the commencement and financing of an appropriate environmental review, and payment of fees are filed with the Colusa County Groundwater Commission. Within 10 calendar days of filing, the Commission will deliver notice of the filing to the Colusa County Planning Department. A copy of the notice and application will be sent to all local agencies within the county with lands overlying, or adjacent to, the site of the proposed extraction and to any interested party who has made a written request to receive notification within the last 12 calendar months. The Commission will review the permit application for completeness, then commence the environmental review.

The Commission will review the application with potentially affected Colusa County departments and local agencies, state and federal agencies, and with any other potentially affected party. If the applicant has applied to extract groundwater from an area in which a groundwater management plan has been adopted but does not expressly permit the export of water, the Commission shall consider the groundwater management plan and any other information provided by the local agency. Comments from interested persons or agencies must be submitted within 30 days of the mailing date of the notice regarding the filing of the permit application.

A public review is required following completion of the environmental review. Notice of the public review will be in accordance with Government Code §6061. The Commission may establish rules of evidence to expedite the presentation of relevant information. The applicant has the burden of proof of establishing the facts necessary for the Commission to make the required findings. The Commission will hear relevant evidence presented by other interested persons and entities and will approve, deny, or conditionally approve the application within one year. Conditions of approval may address the potential effects on the hydraulic gradient, hydrology, percolation, permeability, piezometric surface, porosity, recharge, annual yield, specific capacity, spreading waters, transmissivity, usable storage capacity, water table, water quality, zones of saturation, and other relevant impacts or findings of the Commission. The Commission may request any additional information it deems necessary for its consideration. The cost of additional information will be incurred by the applicant.

The permit will be granted only if a majority of the total membership of the Commission and a majority of the Commissioners present at the public meeting find that the proposed groundwater extraction will not have the following significant detrimental impacts:

- Cause or increase an overdraft of groundwater underlying Colusa County
- Adversely affect the long-term groundwater storage or transmission characteristics of the aquifer
- Exceed the annual yield of the groundwater underlying the County or otherwise operate to the injury of the reasonable and beneficial uses of overlying groundwater users
- Result in injury to a water replenishment, storage, or restoration project operating in accordance with statutory authorization
- Be in violation of Water Code Section 1220
- Be otherwise detrimental to the health, safety, and welfare of property owners overlying or in the vicinity of the proposed extraction site(s)

The permit will be issued, or denied, following consideration of the proposed export, potential conditions of approval, and the potential of the above impacts from which extraction may result. If the Commission believes that there is a potential for one or more of the above listed impacts, they will deny the permit application. The applicant will be notified in writing within 15 days of the final Commission action. Reapplication for a permit that has been denied may not be filed until the water year (October 1 through September 30) following the denial. Any reapplication must be accompanied by information demonstrating a significant change in circumstances forming the basis of the previous permit denial.

The applicant, or any interested party, may appeal a Commission decision by filing a written request with the Clerk of the Board of Supervisors within 15 days of the issuance of the Commission's decision. The appeal must specifically set forth the procedural and substantive reasons for the appeal. The Board of Supervisors will hear the appeal. Relevant evidence may be presented by the appellant and other interested parties. The permit applicant who is proposing to extract groundwater for exportation has the burden of proof that such extraction is either exempt from the permit requirements of this ordinance or will not have significant detrimental impacts based upon the above criteria. The decision of the Board of Supervisors is final.

If a permit is approved, the Commission will impose appropriate conditions to prohibit overdraft or other adverse conditions and may impose other conditions to promote or maintain the health, safety, and welfare of Colusa County residents. An approved permit is valid for up to three water years (October 1 through September 30) from the date of issuance. The water year in which the permit is granted is not counted in determining this time period if less than four months remain in the water year at the time of final permit approval. However, if the extraction is part of a conjunctive use program approved by the county, the term of the permit may not exceed the length of the term of that program.

During the term of the permit, any interested party may challenge the ongoing extraction of groundwater based on allegations of any of the following conditions:

There has been or is an ongoing violation of one or more conditions of the permit.

The extraction of groundwater has adversely impacted groundwater overdraft conditions, long term storage or transmissivity of the aquifer; exceeds the annual yield of the groundwater basin; operates to the injury of the reasonable and beneficial use of overlying groundwater users; is in violation of Water Code section 1220; or results in an injury to a water replenishment, storage , or restoration project operating in accordance with statutory authorization.

The continued extraction of groundwater will be detrimental to the health, safety, and welfare of one or more affected local agencies or other interested parties.

A challenge to an approved permit may be made by filing a written request with the Colusa County Groundwater Commission on a Commission-prescribed form. Within 10 days of receipt of a completed challenge, the Commission will give notice to the permittee, the appellant, all affected local agencies, and any other interested party that has requested notification. The Commission will then hold a review of the matter. The Commission's decision may be appealed to the Board of Supervisors.

Butte County

Butte County has adopted a groundwater protection ordinance titled "Ordinance to Protect the Groundwater Resources in Butte County." This ordinance requires permits for groundwater substitution and direct water transfers to areas outside of the county.

This ordinance authorizes development of a countywide groundwater monitoring program implemented by the Butte County Water Commission in cooperation with the Technical Advisory Committee, the Butte County Water Users Association, DWR, and the RWQCB. Groundwater levels in monitoring wells will be measured at least four times per year. Data collected will be combined with groundwater data from cities and districts within the county. A groundwater status report based upon this data will be completed by January 15 each year and will be used to guide groundwater planning.

Applications for permits along with requests for environmental reviews are made to the Butte County Water and Resource Conservation Department. The environmental review must be undertaken in accordance with the California Environmental Quality Act and County guidelines. Permits are granted or denied by the Butte County Water Commission. A permit that is denied may be appealed to the Butte County Board of Supervisors.

A permit will be granted only if the Commission finds that the extraction will not:

- cause or increase an overdraft of the groundwater underlying the county,
- bring about or increase salt water intrusion,
- exceed the safe yield of the aquifer or subbasins underlying the county,
- result in uncompensated injury to overlying groundwater users or other water users, or
- cause subsidence.

A second ordinance in Butte County covers the health and safety aspects of water wells and sets restrictions on well spacing based on capacity. This ordinance amends Chapter 23B of the Butte County Code, which is titled 'Water Wells.' This amendment requires permits for construction, repair, deepening, or destruction of any public water supply well or individual well.

Applications for permits are submitted to the Butte County Water Commission. The pumping capacity of the pump for a well required to have a new permit is limited to 50 gallons per minute per acre of land. This ordinance prohibits the construction of drainage wells within the unincorporated area of Butte County. A drainage well is defined as a well that is constructed to dispose of storm water runoff. Permits for recharge or injection wells require written approval from the RWQCB before they will be issued through the county.

Sacramento County

The Sacramento County Water Agency Act, Sections 32 through 33, is State law authorizing the Sacramento County Water Agency to manage surface water and groundwater within groundwater management zones that the Agency may establish within its boundaries. The Agency may levy charges upon the production of groundwater to provide funding for activities that protect and augment water supplies of the water management zones. Annual reports for each water management zone prepared by the Agency engineer will include the following:

- Information on the availability of surface and groundwater in the zone
- The quantity of water needed for surface delivery and for replenishment of groundwater supplies for the ensuing water year
- The amount of water which the Agency is obliged to purchase for use in the zone during the ensuing year
- An estimate of the amount of groundwater to be extracted within the ensuing year for each water management zone

An additional report titled "The Record of Water Production and Groundwater Charges" will also be prepared annually for each zone in which a groundwater charge is levied.

The Sacramento County Water Agency Act authorizes cyclic storage agreements through which public entities and utilities located within, or outside, Sacramento County may enter into contracts with the Agency for use of groundwater storage capacity within groundwater management zones for subsequent recovery by the storing entity.

This law authorizes establishment of a Water Advisory Commission whose duties include (1) advising the Agency Board on water policy, water planning and water development proposals, budget and expenditures, groundwater management programs, and water rights; and (2) conducting initial public hearings on zone formation, hydrologic boundary determinations, groundwater recharge proposals, and other matters.

Yolo County

"Yolo County Ordinance No. 1195 Regarding the Extraction and Exportation of Groundwater from Yolo County (adopted November 26, 1996)" requires a permit for the export of extracted groundwater to areas outside the county. An environmental review in accordance with the California Environmental Quality Act and County guidelines is required.

Permit applications are filed with the Director of Community Development. Upon completion of the environmental review, the Director forwards the application, the environmental documents, written comments, and a recommendation to the Commission. The Yolo County Planning Commission and the Water Resources Association of Yolo County together form the Commission, which hears the application in accordance with provisions for public review. The Commission makes recommendations to the Yolo County Board of Supervisors. The recommendations to the Board of Supervisors are structured so that the Planning Commission and the Water Resources Association can separately indicate approval or disapproval of the recommendations. If the Board of Supervisors denies the permit, a reapplication may not be filed until the following water year and must be accompanied by information that demonstrates a significant change in groundwater conditions and/or change in the proposed extraction.

A permit may be granted only if the Board finds and determines that the extraction:

will not cause or increase an overdraft of the groundwater overlying the County,

will not adversely affect the long-term ability for storage or transmission of groundwater within the aquifer,

will not, together with other extractions, exceed the safe yield of the groundwater underlying the County unless the safe yield is exceeded only by extractions in connection with a conjunctive use program approved by the Board and will not otherwise operate to the injury of the reasonable and beneficial uses of overlying groundwater users, and

is otherwise in compliance with Water Code 1220, will not result in an injury to a water replenishment, storage, or restoration project operating in accordance with statutory authorization.

Reference and Plates

References

Bertoldi, G.L., 1976, Chemical Quality of Groundwater in the Tehama-Colusa Canal Service Area, Sacramento Valley, California: USGS, Water Resources Investigations 76-92. November, 1976.

Berkstresser, C.F., Jr., 1973, Base of fresh water in the Sacramento Valley and Sacramento-San Joaquin Delta, California: U.S. Geological Survey, Open File Report WRI 40-73, Borcalli and Associates, 1995, Princeton-Codora-Glenn Irrigation District and Provident Irrigation District Groundwater Management Plan. Review Draft.

CH2MHILL, 1975, Redding region water supply alternatives for Shasta Co. Water Agency, City of Redding, Enterprise Public Utility District, Cascade Community Services District, and Bella Vista Water District. Engineering Report. August, 1975.

CH2MHILL, October 1989, Test Well Report For Glenn-Colusa Irrigation District.

CH2MHILL and Montgomery Watson, 2000, District Need For Water and Basinwide Water Balance. Draft Technical Memorandum No. 4. February, 2000.

CH2MHILL and Montgomery Watson, 2000a, Sacramento River Basinwide Management Plan – Water Mangement and Supply Options. Draft Technical Memorandum No. 5. February, 2000.

CH2MHILL, Montgomery Watson, and MBK, 2000b, Sacramento River Basinwide Management Plan – Future Water Management Alternatives. Draft Technical Memorandum No. 6. January, 2001.

California Department of Water Resources, 1964, Quality of ground water in California 1961-2, Part 1: Northern and Central California. Bulletin 66-62. August, 1964.

California Department of Water Resources, 1964a, Shasta County Investigation. Bulletin 22.

California Department of Water Resources, 1964b, Shasta County Investigation - Appendices E through P. Bulletin 22.

California Department of Water Resources, 1966, Precipitation in the Central Valley. Sacramento District, Coordinated Statewide Planning Program. Office Report.

California Department of Water Resources, 1968, Water Well Standards - Shasta County. Bulletin 74-8.

California Department of Water Resources, 1975, California Groundwater. Bulletin 118.

California Department of Water Resources, 1978, Evaluation of Groundwater resources: Sacramento Valley. Bulletin 118-6.

California Department of Water Resources, 1980, Groundwater basins in California. Bulletin 118-80.

California Department of Water Resources, 1987, Progress report Sacramento and Redding basins groundwater study. Northern and Central Districts, in Cooperation with U.S. Geological Survey.

California Department of Water Resources, 1990, Colusa basin appraisal. State of California, Northern District. May, 1990.

California Department of Water Resources, 1990, Toxic well water near Maxwell, office memo, Jerry Boles. August, 1990a.

California Department of Water Resources, 1992, Preliminary water analysis for "Pelger" well, State Well Number T13NR02E19D01M, Sutter County. DWR Internal Memo.

California Department of Water Resources, 1992a, Construction and sampling of monitoring wells at WildGoose Club, office memo. Bob Niblack. September, 1992.

California Department of Water Resources, 1994, Normalized 1990 land and water use data for Northern District's Portion of Bulletin 160-93. District Report.

California Department of Water Resources, 1994a, California Water Plan Update. Bulletin 160-93, Vols. 1 & 2.

California Department of Water Resources, 1995, Sacramento Valley groundwater quality investigation. DWR Northern District.

California Department of Water Resources, 1996, Groundwater Levels in the Sacramento Valley Groundwater Basin: Glenn County. Northern District Memorandum

California Department of Water Resources, 1997, American Basin conjunctive use project: feasibility report. Central District. June, 1997.

California Department of Water Resources, 1997a, Lower Colusa basin conjunctive use investigation. State of California, Central District Memorandum.

Curtin,G., 1971, Hydrogeology of the Sutter Basin, Sacramento Valley, California. MS Thesis, University of Arizona.

Fetter, C.W., 1988, Applied Hydrogeology. Merill Publishing Company, Columbus, Ohio. 1988.

Fogelman, R.P. 1978, Chemical Quality of Groundwater in the Central Sacramento Valley, California. USGS Water Resources Investigation 77-133

Fogelman, R.P. 1983, Groundwater quality in the Sacramento Valley, California, water types and potential nitrate and boron problem areas. USGS map.

Fogelman, R.P., 1983a, Dissolved solids concentrations of groundwater in the Sacramento Valley. USGS Atlas map.

Fogelman, R.P. and Evenson, K.D., 1985, Water resources monitoring in the Cottonwood Creek area, Shasta and Tehama Counties, California, 1982-1983. USGS Water Resources Investigations Report 84-4187.

Helley, E. J. & Harwood, D.S., 1985a, Geologic map of the late Cenozoic deposits of the Sacramento Valley and Northern Sierran Foothills, California. USGS Map MF-1790.

Henderson, D.W., K.K. Tanji, J.W. Bigger, and M.M.Iqbal, 1972, Quality of drain waters and factors in drain water reuse in the Sutter Mutual Water Company service area. Department of Water Science and Engineering, University of California, Davis. November, 1972.

Hull, L.C., 1984, Geochemistry of groundwater in the Sacramento Valley, California. U.S. Geological Survey Professional Paper 1401-B. Laurence C. Hull. United States Government Printing Office, Washington 1984.

Ikehara, M.E., 1994, Global positioning system surveying to monitor land subsidence in the Sacramento Valley: -Journal- des Sciences Hydrologiques, Vol. 35, No.5.

Lofgren, B.E., and Ireland, R.L., 1973, Preliminary investigation of land subsidence in the Sacramento Valley: U.S. Geological Survey Open File Report.

Olmsted, F.H., and G.H. Davis, 1961, Geologic features and ground water storage capicity of the Sacramento Valley, California. U.S. Geological Survey Water Supply Paper 1497.

Page, R.W., 1986, Geology of the fresh ground-water basin of the Central Valley, California, with texture maps and sections: U.S. Geological Survey Professional Paper 1401-C, 54 p.

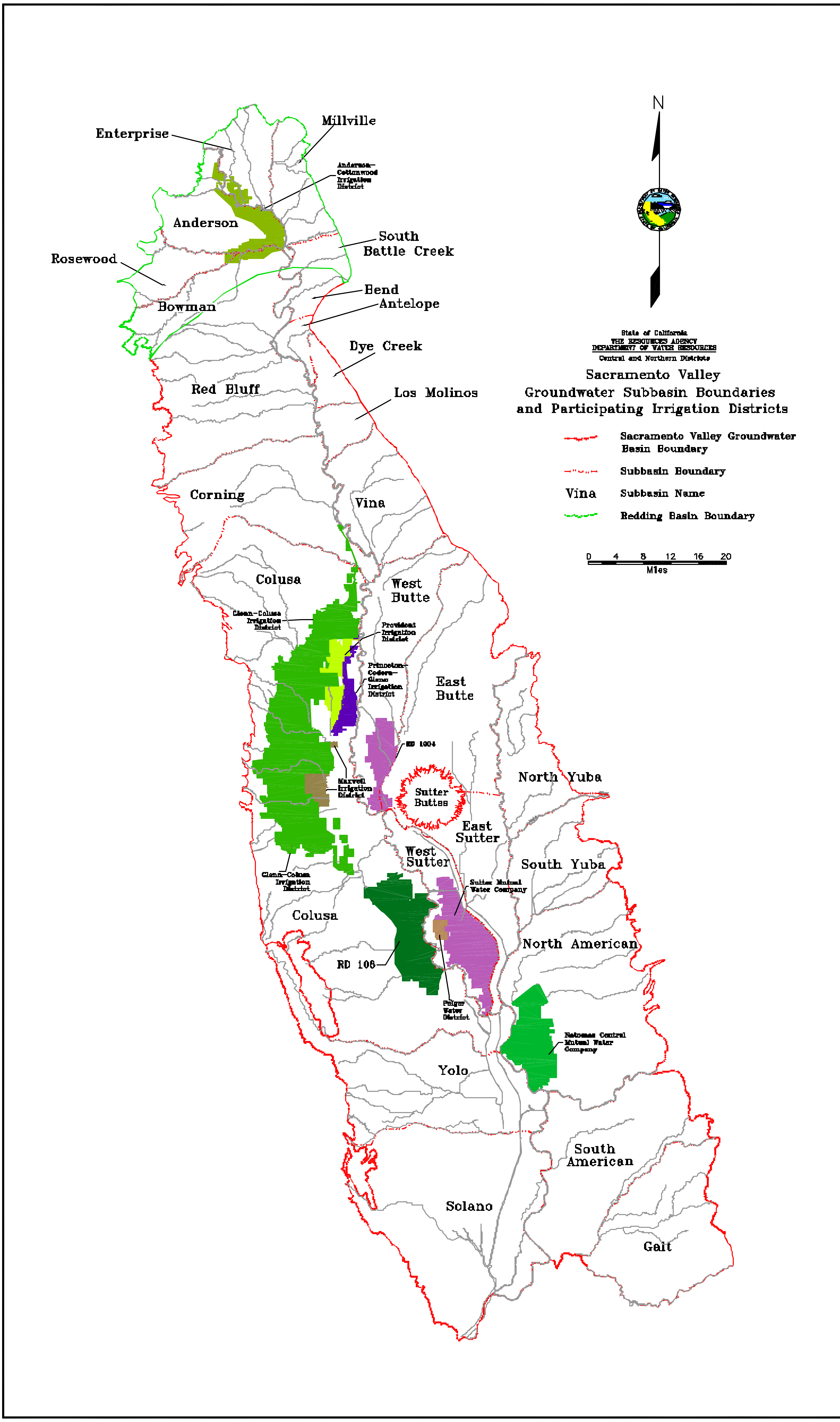
Pierce, M.J., 1983, Ground water in the Redding Basin Shasta and Tehama Counties California. USGS Water-Resources Investigations Report 83-4052.

Russell, Dana, September 1931, The Tehama Formation of Northern California, PhD Thesis, University of California.

State Water Resources Control Board, 1990, Water quality assessment. Division of Water Quality.

Turner, R., 1992. Water-quality sampling at Sacramento National Wildlife Refuges (NWR) – Central Valley Project, California. Memorandum to technical files. United States Bureau of Reclamation. May 1992

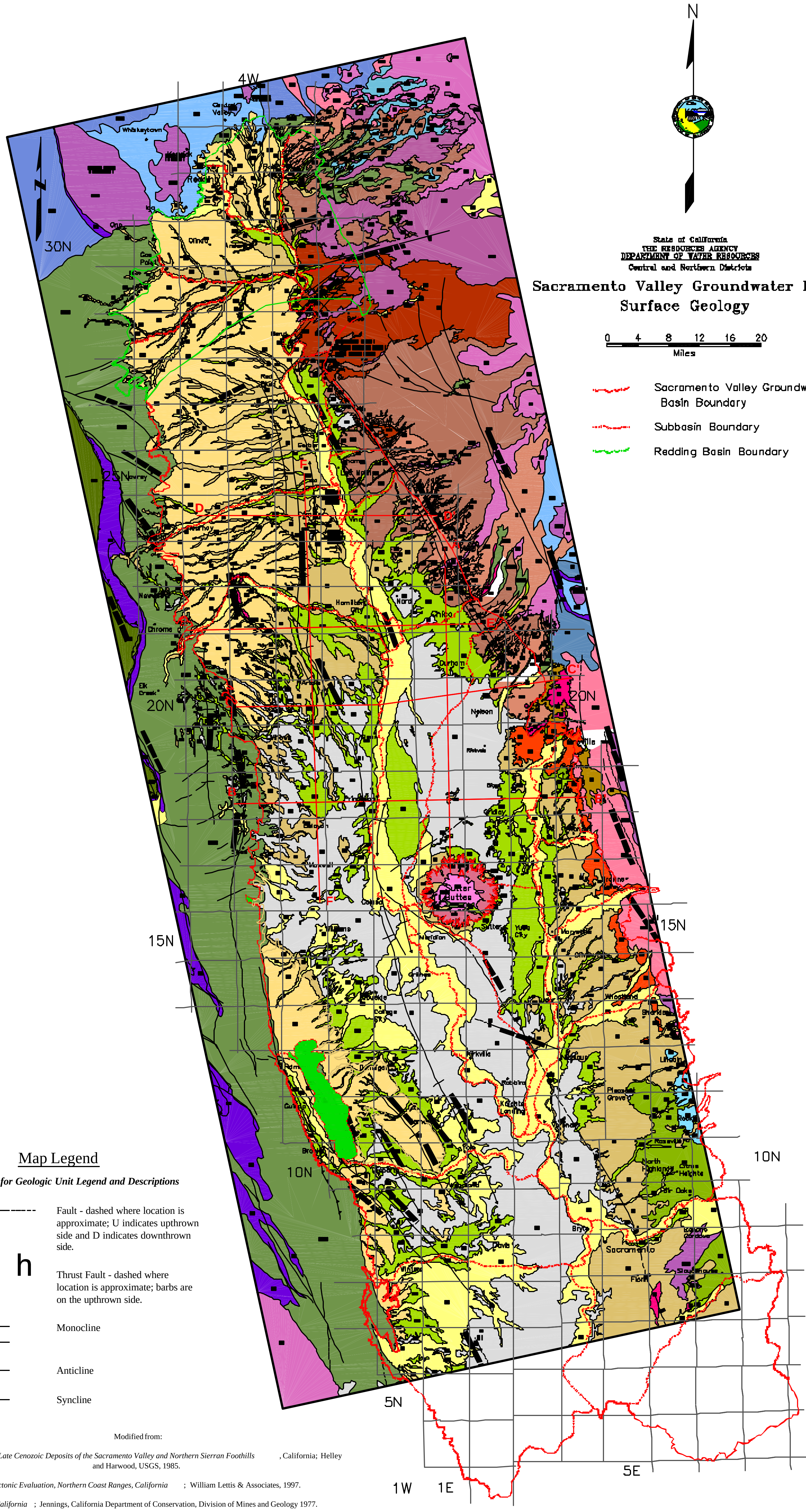
Plate 1



N
State of California
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
Central and Northern Districts
Sacramento Valley
Groundwater Subbasin Boundaries
and Participating Irrigation Districts
Sacramento Valley Groundwater Basin Boundary
Subbasin Boundary
Vina Subbasin Name
Redding Basin Boundary
0 4 8 12 16 20
Miles
Enterprise
Millville
Anderson-Cottonwood Irrigation District
Anderson
South Battle Creek
Rosewood
Bowman
Bend
Antelope
Dye Creek
Red Bluff
Los Molinos
Corning
Vina
Colusa
West Butte
Glenn-Colusa Irrigation District
Provident Irrigation District
Princeton-Codora-Glenn Irrigation District
East Butte
RD 1004
Maxwell Irrigation District
Sutter Buttes
North Yuba
East Sutter
West Sutter
South Yuba
Glenn-Colusa Irrigation District
Sutter Mutual Water Company
Colusa
North American
RD 108
Pelger Water District
Natomas Central Mutual Water Company
Yolo
South American
Solano
Galt

Plate 1

Plate 2



N

State of California
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
Central and Northern Districts

Sacramento Valley Groundwater Basin Surface Geology

0 4 8 12 16 20
Miles

Sacramento Valley Groundwater Basin Boundary

Subbasin Boundary

Redding Basin Boundary

Map Legend

See Plate 2a for Geologic Unit Legend and Descriptions

Fault - dashed where location is approximate; U indicates upthrown side and D indicates downthrown side.

hhh h

Thrust Fault - dashed where location is approximate; barbs are on the upthrown side.

25

Monocline

Anticline

Syncline

Modified from:

Geologic Map of the Late Cenozoic Deposits of the Sacramento Valley and Northern Sierran Foothills, California; Helley and Harwood, USGS, 1985.

Seismotectonic Evaluation, Northern Coast Ranges, California; William Lettis & Associates, 1997.

Geologic Map of California; Jennings, California Department of Conservation, Division of Mines and Geology 1977.

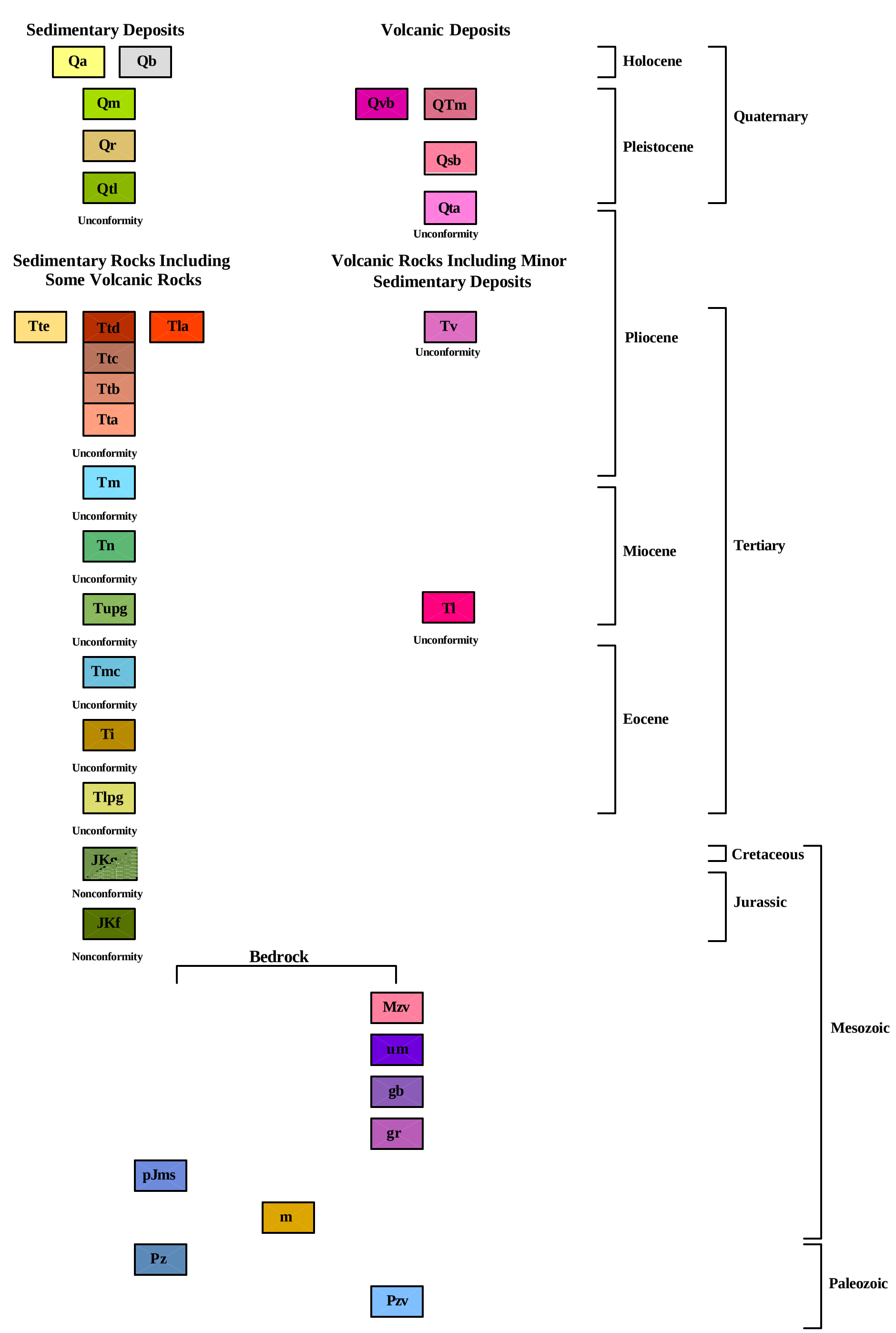
Geologic Map of California, Chico, Ukiah, Redding, and Westwood Sheets; California Department of Conservation, Division of Mines and Geology, 1962.

Plate 2

Plate 2a

Plate 2a

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qa — **Alluvium** (Holocene)-Includes surficial alluvium and stream channel deposits of unweathered gravel, sand and silt, maximum thickness 80 ft. *(adapted from Harwood and Helley, 1985)* .

Qb — **Basin deposits** (Holocene)-Fine-grained silt and clay derived from adjacent mountain ranges, maximum thickness up to 200 ft. *(adapted from Harwood and Helley, 1985)* .

Qm — **Modesto Formation** , undifferentiated (Pleistocene)-alluvial fan and terrace deposits consisting of unconsolidated weathered and unweathered gravel, sand, silt and clay, maximum thickness approximately 200 ft. *(adapted from Harwood & Helley, 1985).*

Qr — **Riverbank Formation** , undifferentiated (Pleistocene)-alluvial fan and terrace deposits consisting of unconsolidated to semi-consolidated gravel, sand and silt, maximum thickness approximately 200 ft. *(adapted from Harwood and Helley, 1985).*

Qtl — **Turlock Lake** (Pleistocene)-weathered and dissected arkosic gravels with minor amounts of resistant metamorphic rock fragments and quartz pebbles, sand and silt; maximum thickness approximately 100 ft. *(adapted from Harwood and Helley, 1985).*

Qvb — **Volcanic Basalts** , undifferentiated (Pleistocene)-younger basalt flows found primarily on the east side of the Sacramento Valley, includes minor exposures of andesite, maximum thickness 100 ft. *(adapted from Harwood and Helley, 1985).*

QTm — **Tuff Breccia** (Pliocene-Pleistocene)-tuff breccia forming outer ring surrounding the Sutter Buttes *(adapted from Harwood and Helley, 1985)* .

Qsb — **Alluvium of the Sutter Buttes** (Pliocene-Pleistocene)-Volcanic fluvatile sediments, maximum thickness 980 ft . *(adapted from Harwood and Helley, 1985).*

Qta — **Volcanic Andesites** , undifferentiated (Pleistocene-Pliocene)-younger andesites forming the center of the Sutter Buttes *(adapted from Harwood and Helley, 1985).*

Tte — **Tehama Formation** (Pliocene)-includes Red Bluff Formation. Pale green, gray and tan sandstone and siltstone with lenses of pebble and cobble conglomerate, maximum thickness 2,000 ft. *(adapted from Harwood and Helley, 1985)* .

Ttd — **Tuscan Unit D** (Pliocene)-Fragmental flow deposits characterized by monolithic masses containing gray hornblende and basaltic andesites and black pumice, maximum thickness 160 ft. *(adapted from Harwood and Helley, 1985).*

Ttc — **Tuscan Unit C** (Pliocene)-Volcanic lahars with some interbedded volcanic conglomerate and sandstone, maximum thickness 600 ft. *(adapted from Harwood and Helley, 1985; DWR (in progress), 2000).*

Ttb — **Tuscan Unit B** (Pliocene)-Layered, interbedded lahars, volcanic conglomerate, volcanic sandstone and siltstone, maximum thickness 600 ft. *(adapted from Harwood and Helley, 1985; DWR (in progress), 2000).*

Tta — **Tuscan Unit A** (Pliocene)-Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone containing metamorphic rock fragments, maximum thickness 400 ft. *(adapted from Harwood and Helley, 1985; DWR (in progress), 2000).*

Tla — **Laguna Formation** (Pliocene)-Interbedded alluvial gravel, sand and silt, maximum thickness 450 feet. *(adapted from Harwood and Helley, 1985; Olmsted and Davis, 1961; DWR Bulletin 118-6, 1978).*

Tv — **Basalts and andesites** , undifferentiated (Pliocene)-older basalts and andesites found on the northeastern portion of the Sacramento Valley and southwest of Winters, maximum thickness up to 230 ft. *(adapted from Harwood and Helley, 1985)* .

Tm — **Mehrten Formation** (Upper Miocene to Middle Pliocene)-Fluvatile andesitic sands and volcanic tuffaceous andesitic sandstone, interbedded with clay and tuff breccia, max. thickness 500 ft. *(adapted from Olmsted and Davis, 1962; DWR Bulletin 118, 1978)* .

Tn — **Neroly Formation** (Miocene)-marine to non-marine sediments, tuffaceous andesitic sandstone with interbeds of tuff and tuffaceous shales and occasional conglomerate lenses, max. thickness 500 ft. *(adapted from Redwine, 1972; Wagner and Saucedo, 1990)* .

Tupg — **Upper Princeton Gorge** (Miocene)-Non-marine sediments composed of sandstone with interbeds of mudstone and occasional conglomerate and conglomerate sandstone, maximum thickness 1,400 ft. *(adapted from Redwine, 1972)* .

Tl — **Lovejoy Basalt** (Miocene)-Black, dense, hard microcrystalline basalt, maximum thickness 65 feet. *(adapted from Harwood and Helley, 1985).*

Tmc — **Montgomery Creek Formation** (Eocene)-Massive to thick-bedded nonmarine sandstone with lenses of pebble conglomerate and shale, maximum thickness up to 650 ft. *(adapted from Harwood and Helley, 1985)* .

Ti — **Ione Formation** (Eocene)-Marine to non-marine deltaic sediments, light colored, commonly white conglomerate, sandstone and siltstone, which is soft and easily eroded, max. thickness 650 ft. *(adapted from DWR Bulletin 118-6, 1978; Creely, 1965).*

Tlpg — **Lower Princeton Gorge** (Eocene)-includes Capay Formation. Marine sandstone, conglomerate and interbedded silty shale, maximum thickness 2,400 ft. (*adapted from Redwine, 1972*)

JKgv — **Great Valley Sequence** (Late Jurassic to Upper Cretaceous)-Marine clastic sedimentary rock consisting of siltstone, shale, sandstone and conglomerate, maximum thickness 15,000 ft.

JKf — **Franciscan Complex** (Jurassic-Cretaceous)-Sandstone with minor exposures of limestone, chert, shale and conglomerate, *(adapted from Jennings, 1977*).

Mzv — **Volcanic and Metavolcanic Rocks** (Mesozoic)-Undivided volcanic and metavolcanic rocks, andesite rhyolite flow rocks, greenstone, and volcanic breccia. (*adapted from Jennings, 1977*).

um — **Ultramafic Rocks** (Mesozoic)-Primarily composed of serpentine, with peridotite, gabbro, and diabase. (*adapted from Jennings, 1977*).

gb — **Gabbro** (Mesozoic)-Gabbro and dark diotric rocks. (*adapted from Jennings, 1977*).

gr — **Undifferenciated Granitic Plutons** (Paleozoic-Mesozoic)-Undivided granitic plutons and related rocks. (*adapted from Jennings, 1977*).

pJms — **Pre-Jurassic Marine Sediments** (pre-Jurassic)-Undifferenciated marine sediments including shales and sandstones, and various undifferenciated schists. (*adapted from Jennings, 1977*).

m — **Mixed Rocks** (pre-Cenozoic)-Undivided metasedimentary and metavolcanic rocks of greatly varying types. (*adapted from Jennings, 1977*).

Pz — **Paleozoic Metasedimentary Rocks** (Paleozoic)-Undivided metasedimentary rocks including slate, shale, sandstone, chert, conglomerate, limestone, dolomite, marble, phyllite,schist, hornfels, and quartzite. (*adapted from Jennings, 1977*).

Pzv — **Paleozoic Metavolcanic Rocks** (Paleozoic)-Undivided metavolcanic rocks, primarily flows, breccia, and tuff, including greenstone, diabase and pillow lavas. (*adapted from Jennings, 1977*).

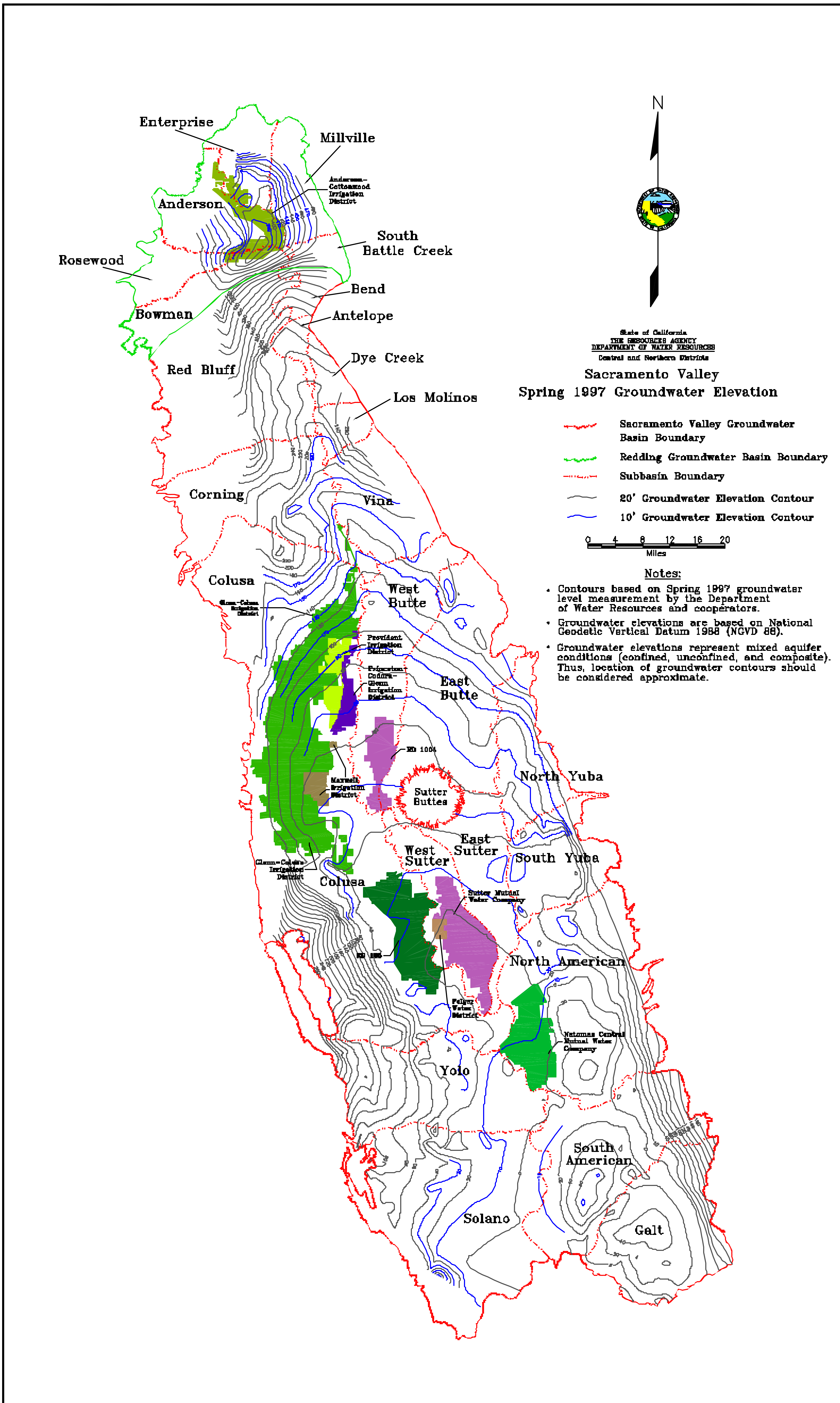
N

State of California
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
Central and Northern Districts

GEOLOGIC LEGEND

Surface Geology

Plate 3



Enterprise
Millville
Anderson-Cottonwood Irrigation District
Anderson
South Battle Creek
Rosewood
Bend
Bowman
Antelope
Dye Creek
Red Bluff
Los Molinos
Corning
Vina
Colusa
West Butte
Glenn-Colusa Irrigation District
Provident Irrigation District
Princeton-Codora-Glenn Irrigation District
East Butte
RD 1004
North Yuba
Maxwell Irrigation District
Sutter Buttes
East Sutter
West Sutter
South Yuba
Glenn-Colusa Irrigation District
Colusa
Sutter Mutual Water Company
North American
Feather Water District
Natomas Central Mutual Water Company
Yolo
South American
Solano
Galt
N
State of California
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
Central and Northern Districts
Sacramento Valley
Spring 1997 Groundwater Elevation
Sacramento Valley Groundwater Basin Boundary
Redding Groundwater Basin Boundary
Subbasin Boundary
20' Groundwater Elevation Contour
10' Groundwater Elevation Contour
0 4 8 12 16 20
Miles
Notes:
• Contours based on Spring 1997 groundwater level measurement by the Department of Water Resources and cooperators.
• Groundwater elevations are based on National Geodetic Vertical Datum 1988 (NGVD 88).
• Groundwater elevations represent mixed aquifer conditions (confined, unconfined, and composite). Thus, location of groundwater contours should be considered approximate.

Plate 3

Plate 4

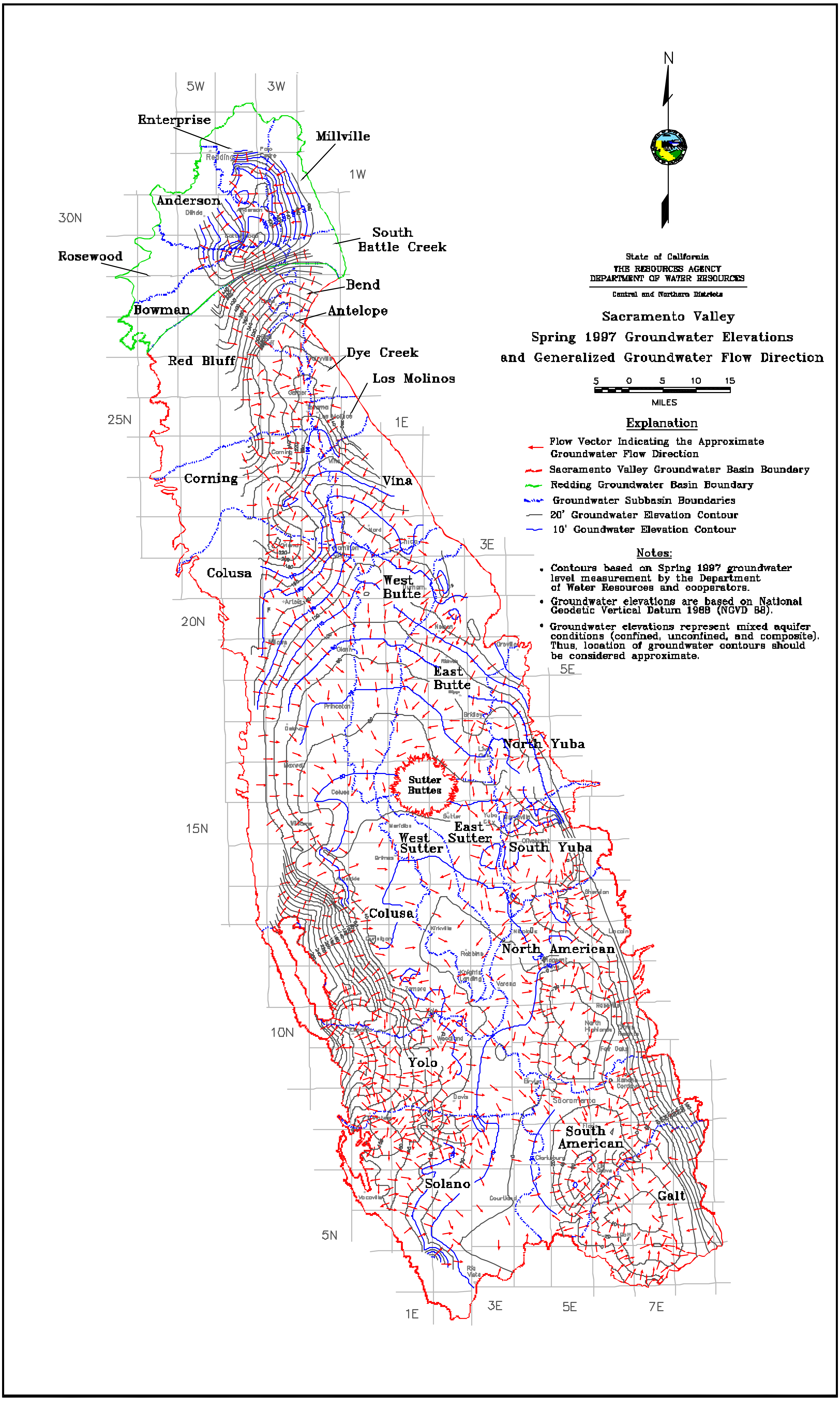

State of California
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
Central and Northern Districts
Sacramento Valley
Spring 1997 Groundwater Elevations
and Generalized Groundwater Flow Direction
5 0 5 10 15
MILES
Explanation
Flow Vector Indicating the Approximate Groundwater Flow Direction
Sacramento Valley Groundwater Basin Boundary
Redding Groundwater Basin Boundary
Groundwater Subbasin Boundaries
20' Groundwater Elevation Contour
10' Goundwater Elevation Contour
Notes:
Contours based on Spring 1997 groundwater level measurement by the Department of Water Resources and cooperators.
Groundwater elevations are based on National Geodetic Vertical Datum 1988 (NGVD 88).
Groundwater elevations represent mixed aquifer conditions (confined, unconfined, and composite). Thus, location of groundwater contours should be considered approximate.
N
5W
3W
1W
30N
25N
20N
15N
10N
5N
1E
3E
5E
7E
Enterprise
Millville
Anderson
South Battle Creek
Rosewood
Bend
Bowman
Antelope
Red Bluff
Dye Creek
Los Molinos
Corning
Vina
Colusa
West Butte
East Butte
North Yuba
Sutter Buttes
East Sutter
West Sutter
South Yuba
Colusa
North American
Yolo
South American
Solano
Galt

Plate 4

Plate 5

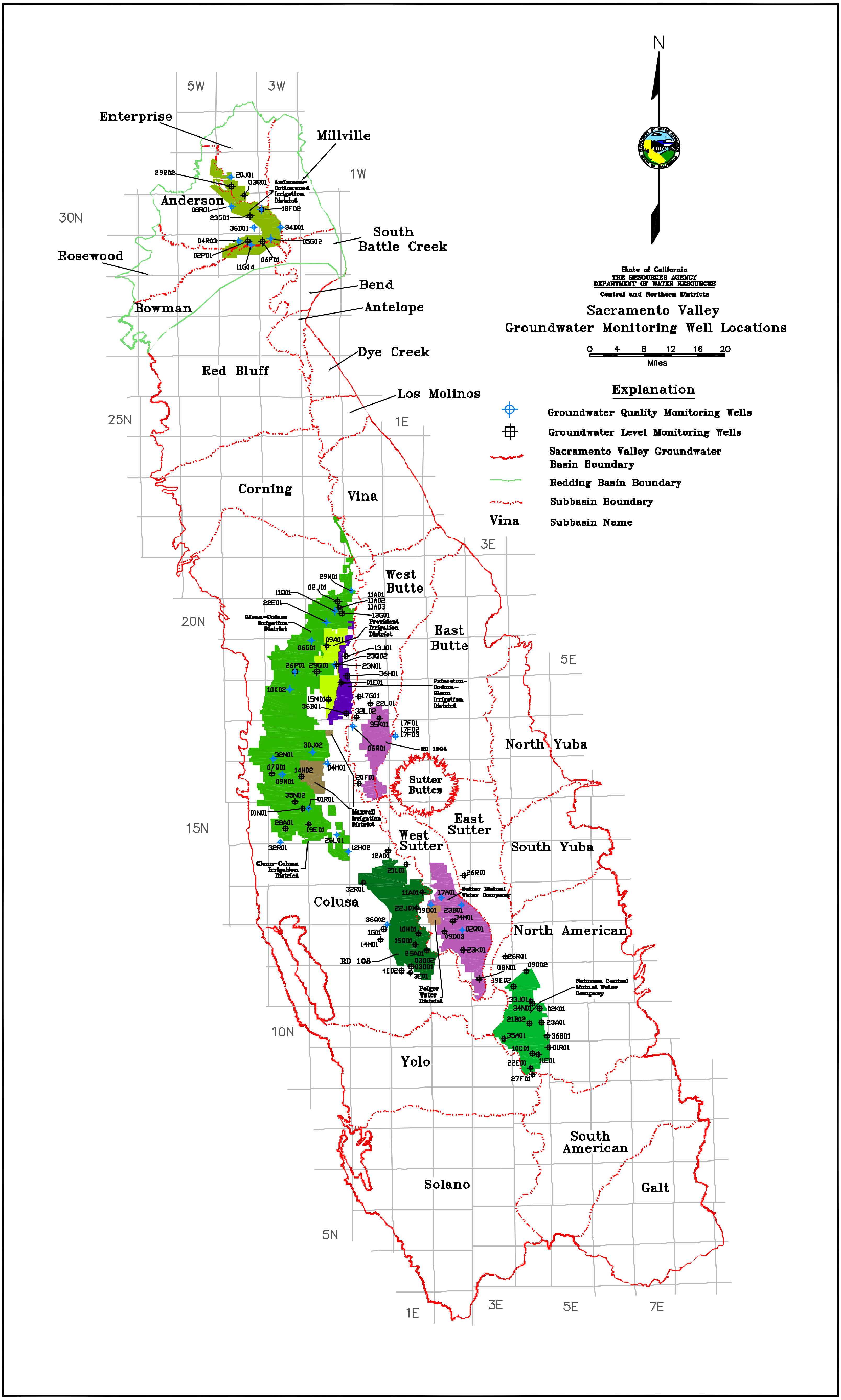

State of California
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
Central and Northern Districts
Sacramento Valley
Groundwater Monitoring Well Locations
0 4 8 12 16 20
Miles
N
Explanation
Groundwater Quality Monitoring Wells
Groundwater Level Monitoring Wells
Sacramento Valley Groundwater Basin Boundary
Redding Basin Boundary
Subbasin Boundary
Vina
Subbasin Name
Enterprise
Millville
Anderson
Rosewood
South Battle Creek
Bowman
Bend
Antelope
Dye Creek
Red Bluff
Los Molinos
Corning
Vina
West Butte
East Butte
North Yuba
Sutter Buttes
East Sutter
West Sutter
South Yuba
Colusa
North American
Yolo
South American
Solano
Galt
RD 108
5W
3W
1W
30N
25N
1E
20N
3E
5E
15N
10N
5N
1E
3E
5E
7E

Plate 5

AB	Assembly Bill
ACID	Anderson-Cottonwood Irrigation District
af	Acre Feet
BMO	Basin Management Objective
BWMP	Basinwide Water Management Plan
CEQA	California Environmental Quality Act
CVPIA	Central Valley Project Improvement Act
DWR	California Department of Water Resources
EPA	Environmental Protection Agency
Ft	Foot, Feet (or)
GCID	Glenn-Colusa Irrigation District
GPM	Gallons Per Minute
GPS	Global Positioning System
mg/L	Milligrams per Liter
MID	Maxwell Irrigation District
MOU	Memorandum Of Understanding
NCMWC	Natomas Central Mutual Water Company
PCGID	Princeton-Codora-Glenn Irrigation District
PID	Provident Irrigation District
PMWC	Pelger Mutual Water Company
PMWC	Pelger Mutual Water Company
RD	Reclamation District
RD 108	Reclamation District 108
RD 1004	Reclamation District 1004
RWQCB	Regional Water Quality Control Board
SAR	sodium absorption ratio
SAWF	Sacramento Area Water Forum
SMWC	Sutter Mutual Water Company
SNAGMA	Sacramento North Area Groundwater Management Authority
SRSC	Sacramento River Settlement Contractors
TAF	Thousand Acre Feet
TDS	Total Dissolved Solids
TM	Technical Memorandum
ug/L	Micrograms per Liter
USBR	United. States. Bureau of Reclamation
USGS	United States Geological Survey
WCWD	Western Canal Water District
YCFC&WCD	Yolo County Flood Control & Water Conservation District